IN TWO SECTIONS—SECTION ONE

TRANSACTIONS

of The American Society of Mechanical Engineers

JANUARY, 1935

VOL. 57, NO. 1

Published by The American Society of Mechanical Engineers

TRANSACTIONS

of The American Society of Mechanical Engineers

Published on the tenth of every month, except March, June, September, and December

Publication Office, 20th and Northampton Streets, Easton, Pa.
Editorial Department at the Headquarters of the Society, 29 West Thirty-Ninth Street, New York, N. Y.

Includes Aeronautical Engineering

Entered as second-class matter March 2, 1928, at the Post Office at Easton, Pa., under the act of August 24, 1912. Price $1.50 a copy, $12.00 a year; to members and affiliates, $1.00 a copy, $7.50 a year. Changes of address must be received two weeks before they are to be effective on our mailing list. Please send old, as well as new, address.

The Elastic Properties of Steel at High Temperatures[1]

By GUY VERSÉ,[2] ANN ARBOR, MICH.

This paper deals with the determination of the modulus of elasticity and of the modulus of rigidity of steel at elevated temperatures up to 500 C.

Both a static and a dynamic method were used and their results are compared. Whereas previously most of the static determinations of these moduli have been made under increasing load, in the tests described in this paper they were determined under decreasing load, according to the method proposed by F. L. Everett. The tests show that within certain limits the results obtained by this method are practically independent of the rate of loading. This appears to be due to a strain-hardening effect occurring upon loading and detected upon unloading.

The comparison between the static and the dynamic tests shows that the values of E, modulus of elasticity, and G, modulus of rigidity, determined statically under decreasing load are close to the values obtained dynamically. However they are somewhat lower for temperatures above 400 C.

The values obtained for E and G by static tests under increasing load are not reliable owing to the difficulty of discriminating between the elastic and the plastic deformation.

The values determined dynamically are the most reliable.

The variation of Poisson's ratio with temperature is also presented, the values of μ being obtained by calculation from the values found for E and G.

THE need for more research relating to the determination of the elastic properties of steel at high temperatures has been pointed out in recent years by many investigators and designers of power-plant equipment.

The question, however, has been given attention for a considerable time. As early as 1877, Pisati investigated Young's modulus for iron up to 300 C, and expressed his results by means of a third-degree empirical formula which shows a gradual decrease of the modulus as the temperature rises.

The existence of non-elastic or permanent deformations, of increasing importance with rising temperature, was soon discovered and many investigators have attempted to eliminate the time effect and determine the modulus of elasticity by measuring the so-called instantaneous strain.

Further, when the phenomenon of the continuous creep of metals at high temperatures was discovered, the attention of the investigators became focused on the determination of creep characteristics and it appeared to many that it was impossible to arrive at any definite value for the modulus at high temperatures.

In researches undertaken at the Westinghouse Research Laboratories in 1923, S. Timoshenko found that if the material be previously loaded and an appreciable strain-hardening produced the rate of creep occurring under a load smaller than this initial load was considerably reduced. This takes place to a sufficient extent in some cases, to permit the determination of the elastic deformation with reasonable accuracy. It will be shown that this phenomenon can be explained on the basis of the ordinary creep curves.

F. L. Everett,[3] in his determinations of the modulus of rigidity of a medium-carbon steel up to 500 C, used the original scheme of determining the modulus on unloading rather than on loading.

Because of observations by Honegger,[4] of the Brown, Boveri & Co., Switzerland, it was felt that an investigation of the possibilities and limitations of this scheme would be of value. Dynamic determinations of the moduli have been made also and their results compared with those obtained statically.

Testing Equipment and Test Procedure

(1) *Static Tensile Tests.* A sketch of the apparatus used for the static tensile tests is presented in Fig. 1. Its principle can

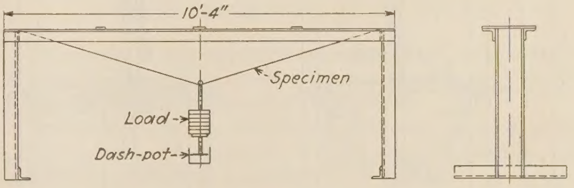


Fig. 1 Tensile Test Apparatus

readily be seen, namely, the specimen is in the form of a wire rigidly fixed at both ends and loaded at the middle. The deflections of the middle-point under various loads are measured by a cathetometer. The heating of the specimen is produced by an electric current passing through it and its temperature is determined by measuring its electrical resistance.

A number of considerations lead to the adoption of such a scheme:

(a) The system is one of great simplicity involving no delicate measuring device

(b) No part of the measuring instruments is subjected to high temperature

(c) Measurement of an elongation of 1.5×10^{-6} is obtained by using an instrument with no greater sensitivity than a cathetometer. This is due to the fact that small

[1] This paper is a portion of a dissertation presented for the degree of Doctor of Science in the University of Michigan. The experimental program was conducted in the Applied Mechanics Laboratory under the direction of Prof. S. Timoshenko.

[2] Associated with Sté. Ame. des Ateliers de Construction Mécanique de Tirlemont, Belgium. Dr. Versé was graduated from the University of Brussels, Belgium, in 1931, with the degree of Ingenieur Civil des Mines. He devoted two years to graduate studies at the University of Michigan as holder of a fellowship of the Commission for Relief in Belgium Educational Foundation, Inc.

Contributed by the Applied Mechanics Division and presented at the Annual Meeting, New York, N. Y., December 4 to 8, 1933, of The American Society of Mechanical Engineers.

[3] "Strength of Materials Subjected to Shear at High Temperatures," by F. L. Everett, Trans. A.S.M.E., vol. 53 (1931), paper APM-53-10.

[4] "The Modulus of Elasticity of Steel at High Temperatures," by E. Honegger, *Brown Boveri Review*, vol. 19, no. 5 (1932), p. 1.

elongations of the wire result in appreciable deflections of the middle-point

(*d*) The method of heating is very simple and the specimen reaches the required stable temperature in a short time.[5]

The electric current was supplied by a large battery set kept on charge during the entire test. In order to prevent air currents from producing temperature variations and to cut down the radiation, asbestos tubing was placed around the wire.

The stress and the strain were easily calculated from geometrical considerations, admitting that the shape of the loaded

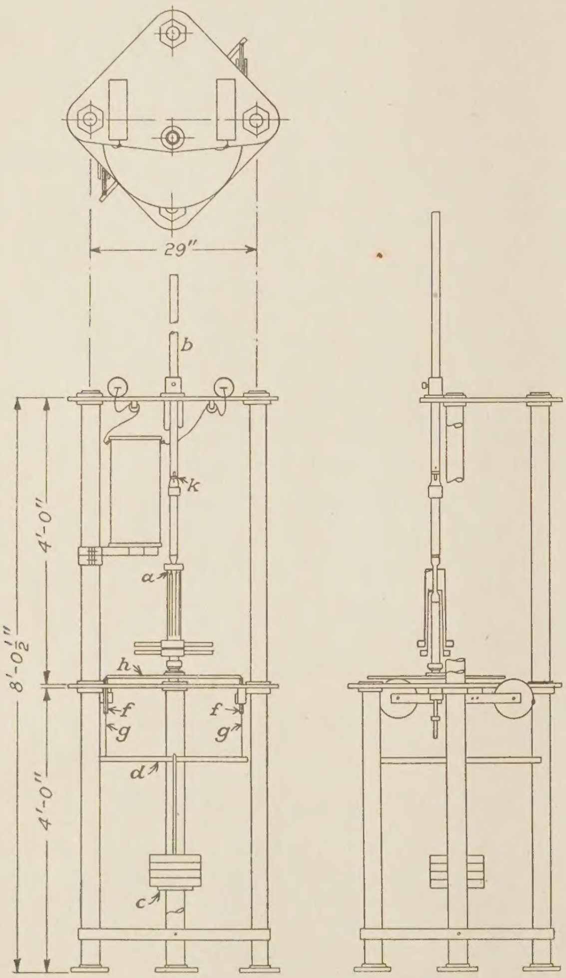


Fig. 2 Torsion Test Apparatus

wire is composed of two straight lines forming an angle at the loading point. A relatively large initial sag, at least one-tenth of the span, was thus resorted to.

The load was applied and removed by steps at the following rates:

about 2500 lb per sq in. every 3 min
about 2500 lb per sq in. every 5 min
about 2500 lb per sq in. every 10 min

The measurements of the deflection were taken 10 sec after the application of the load and at the end of the loading period, that is, 3 minutes, 5 minutes, or 10 minutes after the application of the load, depending on the rate of loading.

(2) *Static Torsion Tests.* The apparatus used in making the static torsion tests was designed by F. L. Everett for his researches on the strength of materials submitted to shear at high temperatures. The essential features of this machine are shown in Fig. 2. A description of it will be found in a paper presented by Dr. Everett.[3]

The load was applied and removed by steps at the following rates:

1575 lb per sq in. every 2 min
1575 lb per sq in. every 5 min
1575 lb per sq in. every 10 min

Measurements of the shear strain were taken 10 seconds after the application of the load and at the end of the loading period.

(3) *Dynamic Tensile Tests.* In the dynamic tests, the values of E and G were arrived at by determining the period of

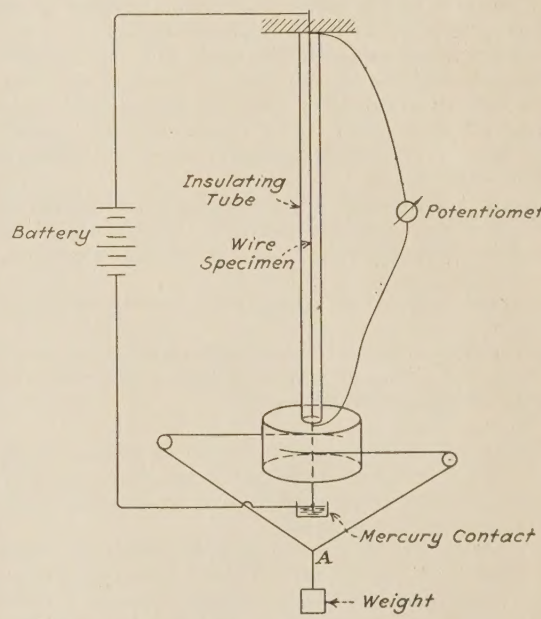


Fig. 3 Apparatus to Measure G Dynamically

free longitudinal and free torsional vibration of a wire. Since the stresses were kept very low it is considered that the amount of plastic deformation taking place in each cycle was negligible. Thus the moduli of elasticity and of rigidity were calculated from the observed periods of free vibration by the well-known formulas based on Hooke's law of elasticity.

For the dynamic tensile tests the same apparatus as for the static tension tests, and shown in Fig. 1, was used except that the horizontal plate of the damper was replaced by vertical fins. The wire, loaded at the middle, is given a first vertical impulse and the free vibrations so produced are recorded on a drum rotating at a known constant speed. The period of free vibration can thus be measured on the record.

The method of heating and of measuring the temperature are the same as for the static tensile tests.

(4) *Dynamic Torsion Tests.* The principle used for the determination of the period of free torsional vibration involves the apparatus shown diagrammatically in Fig. 3 and is as follows: A couple is applied at the lower end of a wire hanging vertically and

[5] From the experiments of H. L. Dodge, *Physical Review*, vol. 2, series 2, p. 431, in which the heating was produced alternately by an electric current and by external source, it has been proved that heating by electric current has no effect other than that caused by the accompanying temperature rise.

held fast at the upper end. This couple is suddenly removed by burning the strings at A and free torsional vibrations result. The period of these vibrations is measured by a stop-watch.

The specimen is heated by passing electric current through it. Its temperature is determined by measuring its electrical resistance. The temperature difference between the top and the bottom of the specimen is minimized by the use of a thin copper sheet inside of a glass tube surrounding the wire with asbestos blocking the openings of the tube. Besides, there is an averaging effect along the wire in both the measurements of the temperature and of G.

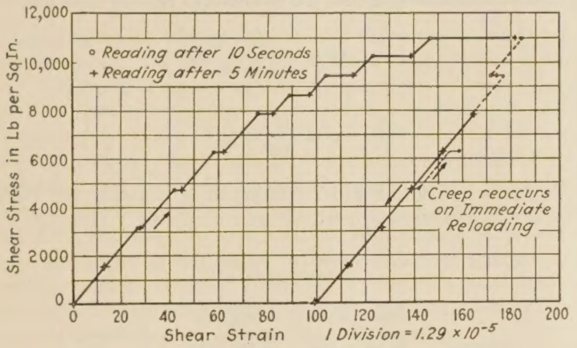


Fig. 4 Torsion Test at 450 C (842 F)

(Load increased every 5 minutes. Rate of unloading: 1575 lb per sq in. every 5 minutes.)

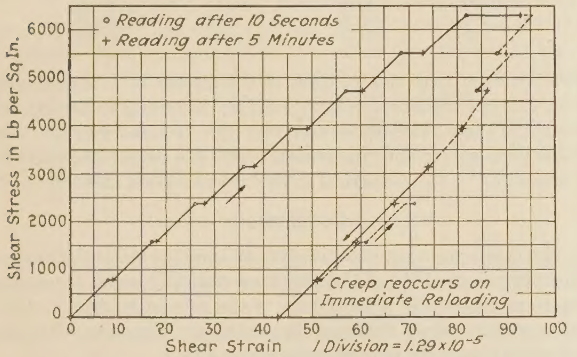


Fig. 5 Torsion Test at 500 C (932 F)

(Rate of loading and unloading: 1575 lb per sq in. every 5 minutes.)

Material Tested

For the static and dynamic tensile tests and the dynamic torsion tests, the specimens were in the shape of a wire 0.0307 in. in diameter and made of carbon steel of the composition:

Carbon	0.43 per cent
Manganese	0.86 per cent
Sulphur	0.038 per cent
Phosphorus	0.018 per cent
Silicon	0.135 per cent

The wire for these tests was annealed before testing.

The static torsion tests were made on tubular carbon-steel specimens of the following composition:

Carbon	0.34 per cent
Manganese	0.80 per cent
Sulphur	0.03 per cent
Phosphorus	0.02 per cent
Silicon	0.10 per cent

The specimens for the static torsion tests were fully annealed by heating to 900 C before testing.

Results

(1) *Static Tests.* The tension tests as well as the torsion tests show that in determining the moduli of elasticity and of rigidity, it is of decided advantage to operate under decreasing rather than under increasing load.

The diagrams, Figs. 4 and 5, for shear at 450 and 500 C are characteristic also of those obtained for tension. It seems that a strain-hardening effect occurring on loading and detected on unloading tends to reduce considerably the amount of plastic deformation taking place in unit time under a certain stress.

It was found also that, within the range of loading rates previously mentioned, the values obtained on unloading for the moduli were independent of the rate of loading and unloading.

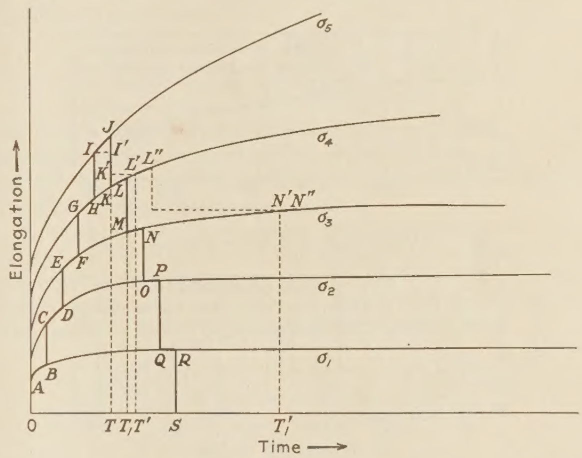


Fig. 6 Time-Elongation Creep Curves

This results in a more reliable determination of the moduli and it is felt that the values obtained under decreasing load are more nearly the physical constants for the material.

The strain-hardening effect is not sufficient, however, to permit an accurate determination, for medium carbon steels, of the moduli at temperatures above 500 C. It is felt that for such temperatures it is better to resort to dynamic tests.

This strain-hardening effect can be explained on the basis of the well-known deformation-time creep curves. It can be seen from Fig. 6 that the step-loading and unloading process used in our experiments can be represented, as far as creep rates are concerned, by the line 0 A B C D E F G H I J K L M N O P Q R S. It can be noticed that, under such a stress as σ_2, the rate of creep CD on loading is much larger than the rate of creep OP on unloading. The restriction "as far as creep rates are concerned" has been made because the line $0AB$—QRS does not give the actual amount of elongation of the specimen after each step. It is easily seen that upon unloading from the stress σ_5 to the stress σ_4 the contraction will not recover the plastic deformation $I'J$ undergone from I to J. Now, even considering the creep rates only, the line $0AB$—QRS is not accurate. Various investigators of the question of creep, Dr. Everett[3] for instance, have shown that the rate of creep under a definite stress is much more a function of the total amount of deformation than of the time. In other words, the total amount of deformation after unloading from σ_5 to σ_4 will not be TK but TK', and the rate at which creep will take place under σ_4 will not be given by KL but by $L'L''$ which is smaller. At the second step of unloading, σ_4 to σ_3, the decrease of creep rate is even larger being from MN to $N'N''$.

TABLE 1 VALUES OF E AND G DETERMINED STATICALLY

Temp, deg C	Modulus of elasticity E, lb per sq in. (millions)	Temp, deg C	Modulus of rigidity G, lb per sq in. (millions)
25	29.9	25	11.53
220	27.5	300	11.1
300	26.9	350	10.7
400	24.5	400	10.0
460	23.0	450	9.15
...	...	500	7.9

TABLE 2 VALUES OF E AND G DETERMINED DYNAMICALLY

Temp, deg C	Modulus of elasticity E, lb per sq in. (millions)	Temp, deg C	Modulus of rigidity G, lb per sq in. (millions)
25	30.2	25	11.55
220	28.4	290	10.9
310	26.9	387	10.3
395	25.7	430	9.73
462	24.2	500	8.5

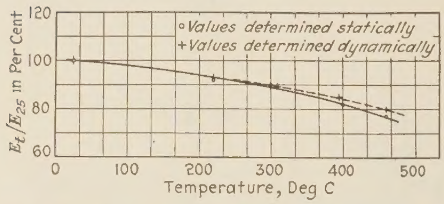


Fig. 7 Variation of E With Temperature

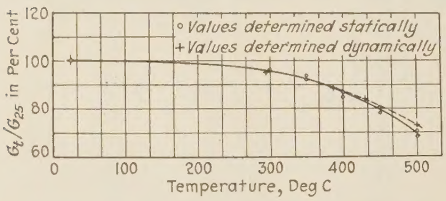


Fig. 8 Variation of G With Temperature

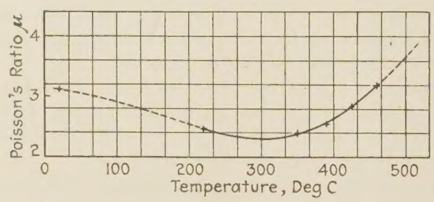


Fig. 9 Variation of μ With Temperature

The values of E and G, determined statically, are given in Table 1.

(2) *Dynamic Tests.* The results of the dynamic tests proved to be more consistent and accurate than those of the static tests, especially at temperatures above 400 C. The cause of this is believed to lie in the fact that the stresses having been kept small, the amount of plastic deformation taking place in each cycle was negligible.

The values of E and G determined dynamically are given in Table 2.

The values of the ratio E_t/E_{25C} as obtained from both static and dynamic tests are plotted against the temperature in Fig. 7. It appears that, for temperatures above 350 C, the values of E_t/E_{25C} when determined statically are somewhat lower than when determined dynamically. The values of the ratio G_t/G_{25C} as obtained from both static and dynamic tests are plotted against temperature in Fig. 8. Again it appears that the values of the static ratio are somewhat lower than the values of the dynamic ratio for temperatures above 400 C.

(3) *Variation of Poisson's Ratio With Temperature.* The theory of elasticity shows that Poisson's ratio μ is related to the modulus of elasticity E and the modulus of rigidity G as follows:

$$G = \frac{E}{2(1 + \mu)}$$

or

$$\mu = \frac{E}{2G} - 1$$

From the values of E and G determined dynamically, the values of μ at various temperatures have been calculated. Although it is fully realized that this method of calculation of μ cannot give very accurate results it is felt that it is interesting to present the results of these calculations (see Fig. 9). It is realized also that these findings are not in agreement with the results obtained by Carrington.[6] The numerical values are presented in Table 3.

TABLE 3 VARIATION OF POISSON'S RATIO WITH TEMPERATURE

Temp, deg C	Modulus of elasticity E, lb per sq in. (millions)	Modulus of ridigity G, lb per sq in. (millions)	Poisson's ratio μ
25	30.2	11.55	0.307
220	28.4	11.4	0.246
300	27.2	11.05	0.23
350	26.3	10.6	0.24
390	25.8	10.23	0.255
425	25.1	9.77	0.283
460	24.2	9.18	0.318

Conclusions

The comparison between the dynamic and the static tests shows that the values of E and G determined statically under decreasing load are practically independent of the rate of loading and are close to the values obtained dynamically. However, they are somewhat lower for temperatures above 400 C.

The values obtained for E and G by static tests under increasing load are not reliable, owing to the difficulty of discriminating between the plastic and the elastic deformation.

It is, therefore, the author's opinion that for the determination of the moduli at high temperatures dynamic tests should always be resorted to. For the application of these results to the calculation of static constructions, such methods as the one presented by K. Baumann[7] should be used in order to take into account the plastic deformation.

Additional experiments are necessary to reach a definite conclusion as to the variation of Poisson's ratio with temperature.

Acknowledgments

The research work reported in this paper was carried out under the direction of Prof. S. Timoshenko. To him the author wishes to express his indebtedness for his invaluable help, advice, and inspiration. Dr. F. L. Everett's and Prof. A. E. White's willingness to give the author the benefit of their own experience on the subject is also greatly appreciated.

[6] *Engineering*, vol. 117 (1924), p. 69.
[7] Ibid., vol. 130 (1930), p. 597.

The Calculation of the Dispersion of Flue Dust and Cinders From Chimneys

By HUBER O. CROFT,[1] IOWA CITY, IOWA

The dispersion of flue dust from a chimney depends primarily upon: (a) the velocity of the flue gas in the chimney; (b) the size and weight of the particle; (c) the height of the chimney; (d) the wind velocity; and (e) the aerodynamic resistance of the particle. The value of the last-mentioned quantity is usually the most uncertain of these variables and is usually obtained from Stokes's equation. Comparisons of different equations for the fluid resistance to falling particles are made in the following article and a new equation is suggested. Using this latter equation and assuming values of the other variables mentioned, a method is demonstrated for calculating the annual dust loading at different distances from a chimney.

MUCH has been written concerning the separation of flue dust from the flue-gas stream by mechanical, hydraulic, or electrical methods, but little has been written about the disposal of that dust and ash which actually reaches the chimney. It is the purpose of this paper to examine the aerodynamics and mechanics of dust-carrying streams and by making certain assumptions, predict approximately what dust particles will be carried up and discharged by a chimney, and further, at what distance from the chimney these particles will be deposited on the earth.

Resistance of Falling Bodies

Heretofore, it has been customary to determine the frontal resistance of falling bodies from Stokes's equation or Allen's equation. In this paper, a new equation is suggested which is the result of the study of numerous falling-body experiments both in liquids and gases.

After the resistance relation has been determined, the time of fall of a particle from a given height may be predicted. Hence, knowing the height of fall and the time of fall, and assuming a wind velocity, the distance a particle can be carried horizontally may be calculated.

Considering a particle falling in still air, the force tending to cause the particle to fall is that of gravity minus the buoyancy of the air. This is opposed by the frontal resistance of the particle, or air friction due to motion. The net force of gravity F can be expressed:

$$F = \frac{\pi\, d^3}{6}\, g\, (\delta - \rho) \qquad [1]$$

where F is the net force of gravity, poundals; d is the diameter of the particle, ft; g is the acceleration of gravity, ft per sec per sec; δ is the unit weight of the particle, lb per cu ft; and ρ is the unit weight of the air in lb per cu ft.

The resistance P of the particle to motion due to air friction can be defined by the equation

$$P = \frac{f}{2}\, \pi \left(\frac{d}{2}\right)^2 \rho V^2 \qquad [2]$$

where P is the air resistance due to motion, poundals; f is the resistance coefficient, a pure number; d is the diameter of the particle, ft; ρ is unit weight of the gas, lb per cu ft; and V is the velocity of the particle, fps.

A falling particle will decelerate rapidly until such a velocity is reached that the net force pulling the particle downward will be just equal to the air resistance to motion of the particle; in which case a constant and maximum downward velocity is obtained. This condition can be expressed mathematically by

$$F = \frac{\pi\, d^3}{6}\, g\, (\delta - \rho) = P = \frac{f}{2}\, \pi \left(\frac{d}{2}\right)^2 \rho V^2 \qquad [3]$$

$$\text{or } f = \frac{4\, d\, g\, (\delta - \rho)}{3\, \rho\, V^2} \qquad [4]$$

where f is the friction coefficient when the maximum velocity is reached.

This maximum, "free-fall," velocity is known as the "end velocity" or "terminal velocity." At such a condition the frontal resistance of the particle is just equal to the force of gravity.

If conditions were reversed, and the atmosphere were to move upward with a speed equal to the end velocity of a particle, the particle would then be supported at a constant elevation by the air velocity.

This end velocity, then, is also the minimum velocity of an upward, vertical, wind stream supporting a given particle. A greater wind velocity than the terminal velocity would carry a given particle upward, because the upward force due to frontal resistance is greater than the force of gravity acting downward upon the particle.

The resistance coefficient, as defined by Equation [2] for regularly shaped bodies, such as spheres, disks, etc., has been studied by many physicists and engineers.

The variation of the resistance coefficient is usually most conveniently demonstrated by plotting this coefficient f as ordinate and Reynolds' number, $\frac{d\, V\, \rho}{\mu} = R$, as abscissa, where μ is the absolute viscosity, lb per ft-sec, and the other symbols are the same as already indicated.

These relations between the resistance coefficients and Reynolds' numbers R are shown in Fig. 1 together with paths of equations expressing certain well-known resistance laws.

---

[1] Head of department of mechanical engineering at the University of Iowa. Mem. A.S.M.E. Professor Croft was graduated from the University of Colorado in 1918 and entered the Air Service at Post Field, Okla. From 1919 to 1921, he was employed by Swift and Company and Durbin Van Law, in Denver. From 1921 to 1927 he was a member of the faculty of the University of Illinois, where he obtained his M.S. degree. In 1927 he became a member of the faculty of Stanford University, and in 1929 was appointed to his present position. Professor Croft has been employed by the City of Saint Louis, the Public Service Company of Northern Illinois, and the Murray Iron Works. He is a member of the A.S.M.E. Power Test Code Committee No. 21.

Contributed by the Fuels Division and presented at the Semi-Annual Meeting, Denver, Colo., June 25 to 28, 1934, of The American Society of Mechanical Engineers.

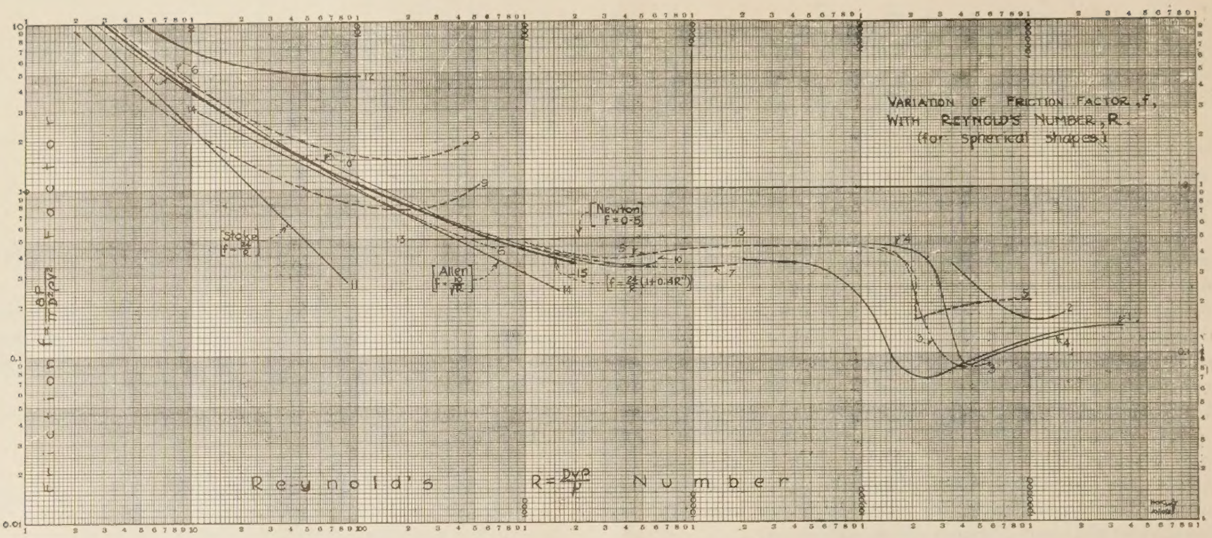


FIG. 1 VARIATION OF RESISTANCE COEFFICIENT f WITH REYNOLDS' NUMBER R FOR SPHERICAL SHAPES

(Curves 1, 3, and 4 are from various wind-tunnel experiments for spheres up to 20-cm diam; curve 2 is for free-falling experiments of spheres from 20 cm to 30 cm diam made of wax, rubber, and wood (3); curve 5 shows the results of experiments by Wieselberger; curve 6 shows the results of falling steel spheres by Liebster (4); curve 7 is for spheres; curves 8 and 9 are for cinders and fly-ash by Rosin and Kayser (5); and 10 gives Allen's results (2). Numbers in parentheses refer to similarly numbered references at the end of the paper.)

The graphs include results obtained from a large number of experimental determinations made with a great variety of particles varying from the resistance of a sphere 20 cm diam, fixed in a wind tunnel, to free-falling rubber spheres about 20 cm diam, and very small spheres in liquids, and cinders in air.

Graphs are also shown for the well-known equations for the gravity separation (sedimentation) of very finely divided particles in liquids. For example, from Stokes's law (1)[2]

$$P = 3\pi \mu d V \quad [5]$$

$$f = \frac{8P}{\pi d^2 \rho V^2} = \frac{24\mu}{d \rho V} = \frac{24}{R} \quad [6]$$

From Oseens' equation (1)

$$P = 3\pi d V\left(1 + \frac{3}{16}R\right) \quad [7]$$

$$f = \frac{8P}{\pi d^2 \rho V^2} = \frac{24}{R}\left(1 + \frac{3}{16}R\right) \quad [8]$$

From Allen's equation (2)

$$f = \frac{10}{\sqrt{R}} \quad [9]$$

From Newton's equation

$$f = 0.5 \quad [10]$$

From Fig. 1 it is seen that apparently there is a distinct connection between resistance determinations on fixed spheres, and the gravity settling of very small particles in liquids as expressed by Equations [5], [7], and [9].

It is further seen that a "critical region" is apparently reached when $R = 100{,}000 \pm$ similar to that in the flow of fluids in pipes when $R = 2000 \pm$ for the pipe condition.

The usual practise in work of this nature for obtaining the friction factor f has been to use different expressions for f for different ranges of R; for example, Kirkup (6) uses Stokes's Equation [6] (curve 11, Fig. 1) as a basis for $R < 8$; Allen's Equation [9] (curve 14, Fig. 1) from $R = 8$ to 450; and Newton's Equation [10] (curve 13, Fig. 1) for $R > 450$.

It is the author's opinion that a single Equation [11] (curve 15, Fig. 1) can be used up to $R = 2000$ without great error. This curve, represented by the heavy line in Fig. 1, has been so drawn that it approaches the curve of Stokes's equation at small values of R, since Stokes's equation is confirmed experimentally for conditions at small values of R.

The equation representing these average conditions is

$$f = \frac{24}{R}(1 + 0.14 R^{0.7}) \quad [11]^3$$

From Fig. 1 it would seem that this equation would give engineering accuracy up to values of $R = 2000$.

Equation [11] and Stokes's Equation [6] result in approximately the same value for f and end velocity up to about $R = 1.0$ (com-

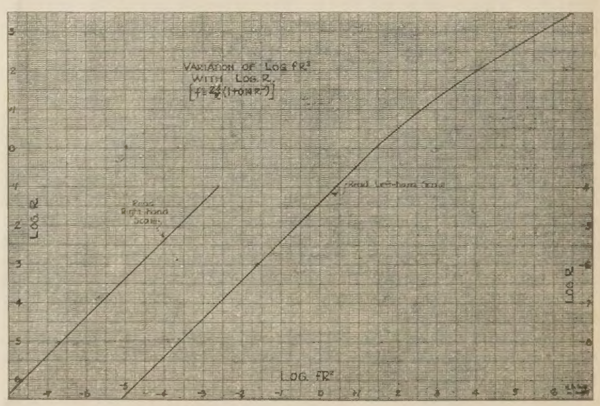


FIG. 2 VARIATION OF LOG fR^2 WITH LOG R

(Value of f as obtained from Equation [11].)

[2] Numbers in parentheses refer to similarly numbered references at the end of the paper.

[3] Schiller and Naumann (7) from less general data express this relation for $R < 800$ as: $f = \frac{24}{R}(1 + 0.15 R^{0.678})$.

TABLE 1 DATA AND METHOD FOR FINDING END VELOCITY

1	Approximate Mesh.	30		100		200		325		1250		2500							
2	Dia. In Microns.	590		149		74		44		10		·5		3		1		0·2	
3	Density of Ash δ – lb./cu.ft.	80		105		120		120		120		120		120		120		120	
4	Flue-Gas Temp. Deg. Fahr.	300	600	300	600	300	600	300	600	300	600	300	600	300	600	300	600	300	600
5	$fR^2 = \frac{4}{3} g \frac{(\delta-\rho)}{\rho \nu^2} D^3$	5850	2230	124	47·2	17.4	6·63	3.61	1·38	·0427	.0163	.00534	·00204	·00115	·000441	0000427	·0000163	$\cdot 341 \times 10^{-6}$	$\cdot 131 \times 10^{-6}$
6	Log. fR^2	3.767	3.48	2.093	1.674	1.241	822	·558	·139	−1.37	−1.788	−2.27	−2.69	−2·94	−3.35	−4.37	−4.787	−6.467	−6.885
7	Log. R	1.89	1.6	0·57	0.20	−1.81	−1.41	−1.16	−2·73	−3·25	−4.8	−4·34	−5·92	−5·68	−5·25	−6·23	−7·81	−8.15	−9·75
8	R	77.6	39.8	3·72	1.585	0.645	0.257	0·145	·0537	.00178	·00063	.000219	·0000831	478×10^{-6}	178×10^{-6}	1.7×10^{-6}	$\cdot 645 \times 10^{-6}$	1.41×10^{-8}	$\cdot 562 \times 10^{-8}$
9	$V = \frac{R\nu}{D}$ (flue-gas)	11·4	11·3	2·17	1.77	·756	·578	.286	.204	·0155	.0105	·0038	·00278	.00138	·000989	.000148	·000107	$6{\cdot}12 \times 10^{-6}$	$4{\cdot}69 \times 10^{-6}$
10	$V = \frac{R\nu}{D}$ (Air)	9.62		2.4		0·9		·332		.0188		·0046		.00165		.000192		8.17×10^{-6}	

Values used: For Flue-Gas – At 300° Fahr., ρ = .0523 lb/ft³; μ = .0000149 lb/ft.sec.; ν = .000285 ft²/sec.
" 600° " , .0373 " ; .0000204 " ; .000547 " .
For Air – " 70° " , .0740 " ; .0000120 " ; .000162 " .

parable to a diameter of 35 microns for this work). For greater values of R, however, Stokes's and Allen's equations result in lower values of f and, hence, greater end velocities. For example, when $R = 400$ (with a 1000-micron particle), the end velocity by Equation [11] is approximately 19.6 fps, while the end velocity from Stokes's Equation [6] is 196 fps for this same diameter.

The relations between f and R for values above $R = 2000$ are rather indefinite because apparently a critical range has been reached in which unstable flow conditions are obtained.

The relations obtained from Fig. 1 between f and R can be transposed to be of great help in the computations involved. From Equation [3], representing the terminal velocity condition

$$\frac{\pi d^3}{6} g\,(\delta - \rho) = \frac{f}{2}\pi\left(\frac{d}{2}\right)^2 \rho V^2 \qquad [12]$$

If both sides of the above equation are multiplied by ρ^2/ν^2, where ν is the kinematic viscosity, we have

$$\frac{4\,g\,d^3}{3\,\nu^2}\left(\frac{\delta - \rho}{\rho}\right) = f R^2 \qquad [13]$$

Equation [13] is useful because the problem is: With a particle of a given diameter and density falling in a gas of known density and viscosity, what is the terminal velocity? Since the factors in the left-hand side of Equation [13] are known, the value of fR^2 can be calculated, and, by referring to Fig. 2, the proper value of R can be determined from the above value of fR^2 and since

$$V = \frac{R\,\mu}{d\,\rho} \qquad [14]$$

the desired end velocity can be calculated.

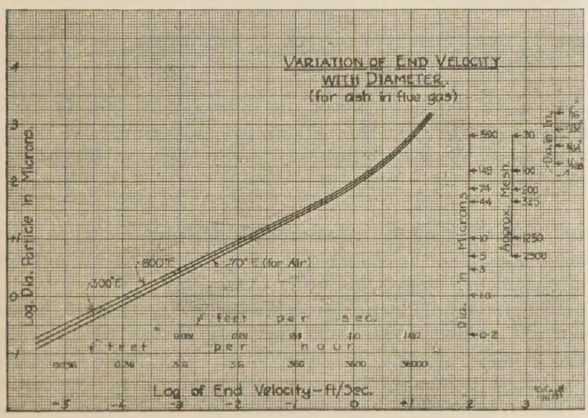


Fig. 3 Variation of End Velocity of Ash in Flue Gas With the Diameter of the Particle

Values for end velocities of different sized particles in flue gas, calculated by this method, can be obtained directly from Fig. 3, which was plotted from the results obtained from the data of Table 1.

The maximum sized particle which can be carried upward by a given flue-gas velocity may also be determined from Fig. 3, since the end velocity determined from this graph is also the flue-gas velocity required to support the particle at a fixed elevation.

Any gas velocity greater than the end velocity will tend to carry the particle upward and out of the chimney; conversely the particle will fall for any gas velocity less than the end velocity.

Time of Fall of Ash Particle When Discharged by Chimney

In order to calculate the time required for an ash particle to fall vertically from the height as discharged by the chimney, certain assumptions are made, namely:

(*a*) The upward velocity of the particle in the chimney may be considered $(U - V)$, where U is the flue-gas velocity, fps, and V is the end velocity of the particle, fps.

(*b*) The upward force of the flue gas becomes negligible when the top of the chimney has been reached.

(*c*) The temperature and the pressure of the surrounding air is constant at 70 F and 14.7 lb per sq in., respectively, for the height of the chimney.

(*d*) The ash particle is similar to a sphere in shape and the diameter of this sphere is the clear distance between the meshes of a screen when meshes are indicated. This assumption is warranted by the results of Rosin and Kayser (5) (curves 8 and 9, Fig. 1) where this approximation is utilized.

The method of making the calculation is best demonstrated by Table 1.

Referring to Table 1, item 1 is the approximate screen mesh corresponding to the diameter of the particle in microns ($1\ \mu = 3.28 \times 10^{-6}$ ft, or $800\ \mu = \frac{1}{32}$ in.). Item 3, the particle density, is varied according to the size (8). Item 5 is calculated from Equation [12]. Item 6 is the logarithm of item 5. Entering Fig. 2 at the value of item 6, item 7 is determined. Item 9, calculated from Equation [14], is then the desired terminal velocity of the ash particle for the condition given in the footnote of Table 1. Item 10 is the terminal velocity of the same particle in air at 70 F and 14.7 lb per sq in. The values obtained from Table 1 are shown plotted for convenience in Fig. 3.

In Table 2 are shown the remaining calculations required for determining the time of descent for the ash particle. This table has been calculated for a flue-gas temperature of 300 F. A flue-gas temperature of 600 F alters the final result less than 1 per cent from that of the same gas at 300 F.

TABLE 2 TIME OF FALL FOR DIFFERENT STACK VELOCITIES AND HEIGHTS

		Approximate Mesh	30				100				200				325				1250				2500											
Stack Vel.		Dia. in Microns	590				149				74				44				10				5				3				1.0			
f.p.s.		Stack Ht.~ft.	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200
10	a	Net Vel.~f/s	0	0	0	0	7.83				9.24				9.71				9.8				←				←				←			
	b	t – Sec.					.245				.287				.303				313				←				←				←			
	c	Max. Ht.~ft.					.96				1.326				1.47				1.56				←				←				←			
	d	Total Fall~ft.					51	101	151	201	51	101	151	201	51	101	151	201	52	102	152	202	52	102	152	202	52	102	152	202	52	102	152	202
	e	Time of fall~Sec.					21.2	42	63	83	56.6	112	169	223	155	304	455	606	2750	5400	8040	10600	11100	21900	32800	43500	31300	61500	91800	2040	4480	8820	13150	17500
20	a	Net Vel.~f/s.	8.6				17.8				19.24				19.7				19.8				←				←				←			
	b	t – Sec.	.27				.556				.597				.616				.626				←				←				←			
	c	Max. Ht.~ft.	1.16				4.95				5.74				6.06				6.26				←				←				←			
	d	Total Fall~ft.	51	101	151	201	55	105	155	205	56	106	156	206	56	106	156	206	56	106	156	206	1256	106	156	206	56	106	156	206	56	106	156	206
	e	Time of fall~Sec.	5.3	10.5	15.6	20.9	23	44	64	85	629	117	173	228	169	319	470	618	2990	5640	8230	11000	12200	22900	33800	44500	34100	64200	94800	2080	4890	9220	13550	17900
30	a	Net Vel. f/s.	18.6				27.8				29.24				29.7				29.8				←				←				←			
	b	t ~ Sec.	.58				.868				.908				.928				.939				←				←				←			
	c	Max. Ht.~ft.	5.4				12.1				13.3				13.8				14.1				←				←				←			
	d	Total Fall~ft.	55	105	155	205	62	112	162	212	63	113	163	213	64	114	164	214	64	114	164	214	64	114	164	214	64	114	164	214	64	114	164	214
	e	Time of Fall~Sec.	5.72	10.9	16.1	21.3	25.9	46.6	67.2	88.2	70.3	126	181	237	192	343	493	642	3410	6060	8700	11400	13800	24600	35500	46300	38900	69200	99600	2120	5530	9900	14250	18600
40	a	Net Vel~f/s.	28.6				37.8				39.24				39.7				39.8				←				←				←			
	b	t ~ Sec.	.89				1.18				1.22				1.24				1.252				←				←				←			
	c	Max. Ht.~ft.	12.7				22.3				23.9				24.6				25.04				←				←				←			
	d	Total Fall~ft.	63	113	163	213	72	122	172	222	74	124	174	224	75	125	175	225	75	125	175	225	75	125	175	225	75	125	175	225	75	125	175	225
	e	Time of Fall~Sec.	6.48	11.7	16.9	22.1	30.1	50.8	71.4	92.4	82	137	193	248	224	376	527	672	3990	6660	9300	11900	16200	27000	37800	48600	45500	75600	1770	2270	6510	10840	15200	19500

Note: Underlined Values in Items "e" = Minutes Instead of Seconds.

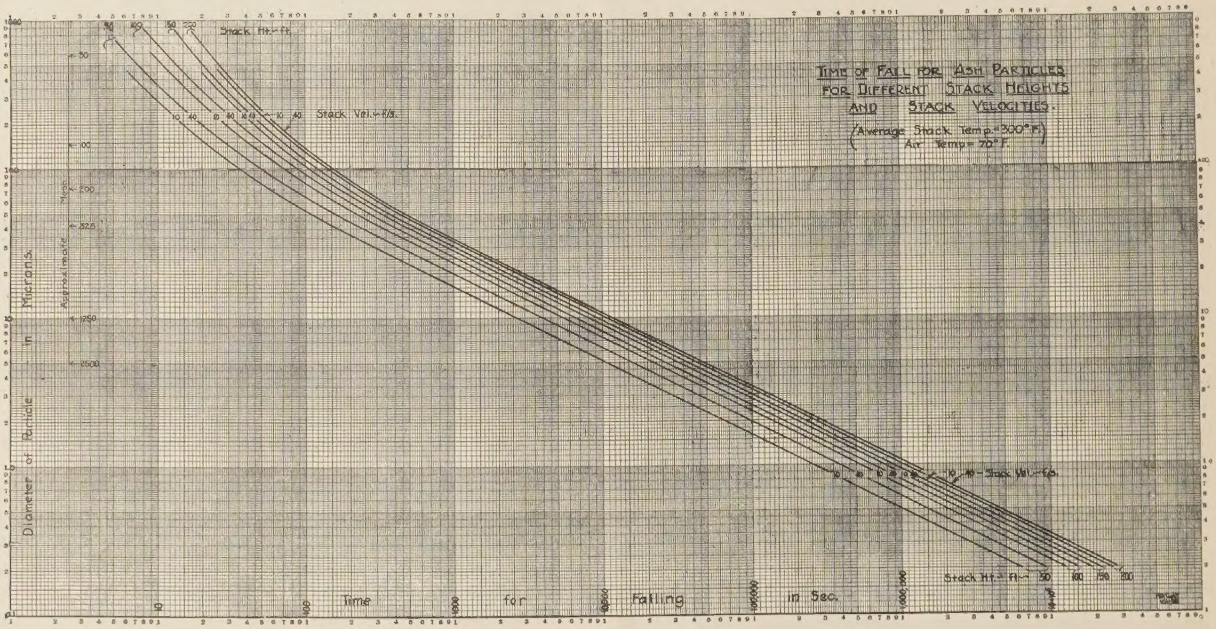


Fig. 4 Time of Fall for Ash Particles for Different Stack Heights and Stack Velocities
(Avg stack temp = 300 F. Air temp = 70 F.)

Chimney velocities of 10, 20, 30, and 40 ft per sec and chimney heights of 50, 100, 150, and 200 ft have been chosen.

Referring to Table 2, item *a* is the net velocity of the particle up the chimney, that is, the flue-gas velocity indicated minus the terminal velocity of the particle in the flue gas (item 9, Table 1).

Item *b* represents the time required for the particle propelled from the chimney to reach the maximum height above the chimney or when the vertical velocity of the particle becomes zero. This is obtained from the equation of falling bodies: $V = -V' + 32t$.

When $V = 0$, V' = the velocity of the ejected particle, item *a*, and t, item *b*, is the required time in seconds. This is an approximation, neglecting the resistance of the particle which introduces a negligible error in the time of fall.

Item *c* is the maximum height above the chimney to which the particle rises and is obtained by multiplying the average velocity of the particle by the time in seconds. Thus, $h = \frac{(V + V')}{2} t$, where $V = 0$ at maximum height. Items *a*, *b*, and *c* are assumed to be constant for particles smaller than 10 microns and at the values given for 10 microns without the introduction of appreciable error.

Item *d*, the total height through which the particle falls, is the sum of the chimney height plus item *c*. This method of calculation does not consider the time required to accelerate the falling particle up to the end velocity, but the error involved is negligible.

Item *e*, the time required for the particle to fall to earth, is the total height, item *d* divided by the end velocity in the air (item 10, Table 1).

The results given in Table 2 are shown plotted in Fig. 4.

For convenience, Fig. 5 illustrates the distance to which different sized particles are carried for different wind velocities: If the chimney is 100 ft high, the chimney velocity is 20 ft per sec, the average flue-gas temperature is 300 F, and the outside air temperature is 70 F. Other data used are the same as in Table 1.

The distance a particle is carried is determined by multiplying the wind velocity in ft per sec by the falling time (obtained from Fig. 4) in seconds for the proper particle size and chimney height.

Application of the Results

A practical problem will now be solved by the use of the foregoing plotted data, showing the methods of approach.

The following data assumed are in no way to be considered an accurate representation of the performances of the different types of firing, or dust-separating equipment. These data are used merely to demonstrate a method of attack.

The assumed data are: Chimney height = 100 ft; chimney velocity = 20 ft per sec; chimney-gas temperature = 300 F; average wind velocity = 5 mph or 10 mph; size of unit = 50,000 kw; lb of coal per kwhr = 1.7; carry-over for stoker = 5 per cent of the coal fired; and carry-over for pulverized fuel = 6 per cent of the coal fired.

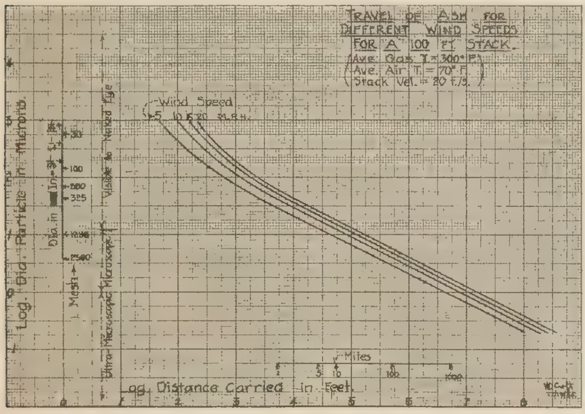


FIG. 5 TRAVEL OF ASH FOR DIFFERENT WIND SPEEDS FOR A 100-FT STACK

(Avg gas temp = 300 F. Avg air temp = 70 F. Stack velocity = 20 fps.)

The assumption is also made that all of this carry-over will be discharged by the chimney in order to calculate the worst condition of loading, although some of the larger sizes would probably be deposited in the breeching and chimney, especially if no induced-draft fan is used and low breeching velocities exist.

The assumed percentage by weight of the various sizes of the carry-over and the assumed efficiency of the separator for each size as well as the resulting calculated yearly loading at different distances are given in Table 3.

The distance that the particle is carried was obtained from Fig. 5.

The dust loading per square foot per year given in Table 3 was obtained by using the distance carried for the largest particle as a radius with the chimney at the center and assuming an equal distribution of the dust for that size over the area of the circle formed.

The distribution of the dust for the next larger size was determined by using the distance carried for this sized particle as a radius of a circle with the chimney at the center, subtracting the area covered by the next larger size, and dividing the total weight of ash for that size by the annular area so formed.

TABLE 3 DISTRIBUTION AND YEARLY DUST LOADING BY CARRYING OVER FROM A 100-FT CHIMNEY

Particle Diameter		Distance Carried by Wind—in ft.		Sep. Eff. %	STOKER—Carry Over = 5% of Coal						PUL. COAL—Carry Over = 6% of Coal					
					Carry Over		Dust Loading in lb. per sq ft. per yr.				Carry Over		Dust Loading in lb per sq. ft per yr.			
							5 M.p.h		10 M.p.h.				5 M.p.h		10 M.p.h	
Mesh	Microns	5 M.p.h.	10 M.p.h.		%	Lb/hr	No Sep.	with Sep.	No Sep.	with Sep.	%	Lb/hr	No Sep.	with Sep.	No Sep.	with Sep.
20	832	56	112	99.9	1.0	42.3	37.6	.038	9.4	.009	0	0	0	0	0	0
50	294	144	288	98.0	4.0	170	26.9	0.54	6.73	.135	1.0	51	8.08	·162	2.02	.040
70	208	220	440	93.0	5·0	213	20.1	1.49	5.57	·390	1.0	51	4.82	·337	1.32	.092
140	104	560	1120	81.0	15·0	228	12.6	2.94	3.12	·580	3.0	153	8.45	1.6	2·05	·39
270	53	1410	2820	70.0	25·0	1325	6.94	2·07	1.73	·518	50	255	1.34	·401	·331	.0994
	30	5000	10,000	61.0	20.0	1133	0.431	0.168	·108	·0421	25	1275	·486	·190	0.122	·0476
	20	11,200	22,000	55.0	15.0	637	·0056	·0025	·0139	·0063	35	1785	0.157	·0706	·039	·0175
1250	10	44,700	88,400	42.0	15·0	637	·003	.0017	·0007	·0004	30	1530	·007	.0041	·001	·00058

50,000 kw. Unit; 1.7 lb. coal/kw-hr. Chimney Velocity = 20 ft./sec.

It should be noted that doubling the chimney height has approximately the same effect as doubling the wind velocity. Therefore, in Table 3 (for a 100-ft chimney), the column headed "10 mph" indicates what might be expected with a 5-mph wind with a 200-ft chimney.

In considering the yearly dust loading indicated by Table 3, it is interesting to note that the yearly rate of erosion is approximately 0.03 lb of earth per sq ft (9).

Conclusions

(1) An equation for the resistance of particles is derived (Equation [11]) which is useful over the entire range of particle sizes usually found in cinders and fly-ash.

(2) A method is demonstrated for calculating the distance an ash particle of a given size may be carried from the top of a chimney with a given wind velocity.

(3) By making certain assumptions, a method of calculating the yearly dust loading at different distances from a chimney is advanced.

References

(1) "Handbook Exp. Physik," Wien-Harms, vol. 4, p. 341.
(2) *Philosophical Magazine*, vol. 50, pp. 324 and 519.
(3) Technical Report No. 185, N.A.C.A.
(4) "Handbook Exp. Physik," Wien-Harms, vol. 4, p. 2.
(5) *Zeit. V.D.I.*, 1931, vol. 75, p. 854.
(6) *Fuel*, 1931, vol. 10, p. 196.
(7) *Zeit. V.D.I.*, 1933, vol. 77, p. 319.
(8) *Combustion*, June, 1933, p. 35.
(9) "Hydrology," by D. W. Mead, McGraw-Hill, p. 324.

Discussion

T. A. MARSH.[4] The Department of Smoke Abatement of the City of Chicago has given much attention to atmospheric conditions, not only in the matter of visible smoke, but also of fly-ash and dust, over a period of years and has thereby been able to draw conclusions and to submit some very definite facts.

It has been our observation that many dust-fall determinations have been unreliable and often misleading, due sometimes to the method of making these observations, and at other times to such factors as increasing or decreasing amounts of coal burned within the district during the period of observation. It must, of course, be recognized that not all of the dust fall is chargeable to fuel burning although dust samples indicate that fuel is the major source.

During 1934, the Department of Smoke Abatement, under Civil Works Administration Project No. 1504 which pertains to

[4] Member, Advisory Board of Engineers, Chicago Department of Smoke Abatement, and Central Division Engineer, Iron Fireman Mfg. Company. Mem. A.S.M.E.

smoke observation and abatement, had allocated to it 175 men, some of whom are engineers of national reputation and of wide experience in this work. The writer is authorized, by the Department, to present to the Society any of the facts or figures from the report compiled by these men.

One of the significant figures of the report is that the tonnage of coal burned in the Chicago district has doubled between 1911 and 1933, yet the amount of smoke in 1933 was only 95 per cent of that of 1911, and the density of the smoke only 49 per cent.

Over this period of time, the changes in smoke produced by classifications are as follows:

Railroads	93 per cent decrease
Power plants	15 per cent decrease
Metallurgical furnaces	61 per cent decrease
Manufacturing plants	1 per cent decrease
Boats	2 per cent decrease
Apartment buildings	1620 per cent increase
Domestic (residences)	900 per cent increase

It is evident that we have mastered the situation in the larger plants, but in the meantime the great increase in the number of apartment buildings and residences has so increased the tonnage of coal burned that these two classes of chimneys have become responsible for a very large proportion of our smoke.

An analysis shows the sources of Chicago smoke to be as follows, in order of importance:

Apartments and large heating plants	43.0 per cent
Power plants	25.4 per cent
Domestic	20.4 per cent
Manufacturing	5.1 per cent
Railroad locomotives	2.8 per cent
Metallurgical and special processes	2.4 per cent
Boats	0.9 per cent

We have therefore logically centered our attention on the apartment buildings and heating plants.

Until the development of small automatic stokers for this field we had no reliable and economically sound weapon with which to attack this increasing source of half the smoke. The small stoker offers a definite solution. Four years ago we therefore wrote into our ordinance that all new plants of 1200 sq ft of steam radiation and over must use automatic firing of some kind, i.e., stokers, oil, or gas. At the present time there are approximately 6000 stokers installed in Chicago, each serving 1200 sq ft of radiating surface or more.

The dust fall in Chicago in tons per square mile per month for every year 1926 to 1932, inclusive, is as follows: 326.41, 390.28, 384.81, 355.02, 323.52, 268.52, and 230.33.

We have thus, due to our active campaign, not only reduced the volume and density of smoke in the City of Chicago, but have reduced the dust fall from a high figure of 390.28 in 1927, to 230.33 in 1932, the reduction being 41 per cent. These figures must, however, be considered in the light of the decrease of industrial coal burned in 1933 as compared to 1928. We are encouraged by the improvement, and, inasmuch as apartment buildings are very rapidly installing stokers purely for economic reasons, we feel that within a few years we shall make a measurable reduction in smoke from that particular group which is the worst offender. The improvements in stoker designs as now being made will further decrease the fly-ash.

The current research work and reports of the Department of Smoke Abatement of the City of Chicago are available to all who are interested in this work and our department will be glad to cooperate to the maximum with other cities or engineers toward improvement of atmospheric conditions.

There has never been any question as to whether stokers abated smoke. There has been a question, however, as to whether stokers actually decrease dust and fly-ash from chimneys. Our surveys indicate that stokers do decrease the dust and fly-ash emission because of decreased tonnage and maintenance of a uniform fuel bed.

Fuel and air distribution are the vital factors in fly-ash emission. Stokers with improper distribution and improper air regulation increase fly-ash. During the past three years sufficient advancement has been made in the art to make as much as a 75 per cent reduction in fly-ash from grates.

Cooperation Between Industrial and Public-Utility Companies in Generating Steam and Electricity

By H. DRAKE HARKINS,[1] WILMINGTON, DEL.

PUBLIC-UTILITY systems in the United States (those having an annual output exceeding 100,000,000 kwhr each during 1932) have an installed generating capacity of 30,700,000 kw, 22,000,000 being steam and 8,700,000 being hydro (1).[2]

Manufacturing plants in 1929 had an installed generating capacity of 7,800,000 kw divided among 17,270 generators averaging about 450 kw each (2). Mines and quarries had 740,000 kw (3) installed in electric generators, bringing the total in industrial plants to 8,540,000 kw. The installed capacity of industrial plants is, therefore, approximately 27.8 per cent of the installed capacity of the larger public-utility systems.

Office buildings, hotels, hospitals, schools and colleges, and the like are not tabulated as manufacturers in the census, but for the purpose of this paper they could be included as industrial plants if the figures were available. Therefore, it is probable that the 27.8 percentage of installed capacity is approximately correct even though the very small utilities are not included.

The generating capacity actually installed in industrial plants is only that which management (unfamiliar with power problems) has seen fit to install with economic conditions as they now are and in the face of strong public-utility sales pressure.

Glenn B. Warren (4) states: "An estimate recently made showed that if all the industrial back-pressure and bleeder turbines manufactured in each of the years 1927 to 1929, inclusive, had been built for 1200 lb initial pressure instead of the 200 to 400 lb pressure for which they were built and arranged to supply the same heat, these turbines would have had an aggregate capacity over and above what they did have equivalent to about one-fifth of all the condensing turbines manufactured in the respective years. Similarly, an extension of this investigation indicated that if all these turbines which were installed to supply heating steam had been of the mercury-vapor-process type and, as before, arranged to supply the same demand for heat, these installations would have had an aggregate capacity over and above what they did have equivalent to almost one-half of that of all the condensing turbines manufactured in the respective years."

The author recently reviewed a proposed electrolytic process which involved the distillation of large quantities of mercury. The mercury vapor could generate twice as much electricity, 12,000 kw, as the electrolytic process required. The industry had no use for the surplus electricity and it could not be credited to the operation. In this instance, the absence of a market for surplus electrical energy hindered industrial progress and technical development.

Table 1, by A. R. Smith (5), shows how an industrial steam flow of 400,000 lb per hr at 200 lb pressure could generate no surplus energy, yet 42,000 kw were obtainable through present technology.

TABLE 1 STEAM FLOW TO INDUSTRIAL—400,000 LB PER HR

Initial steam conditions[a]	Entering evaporator[a]	Exhaust-steam conditions[a]	Electric power
200 lb, 525 F	No evaporator	200 lb, 525 F	None
400 lb, 750 F	No evaporator	200 lb, 625 F	5,970 kw
600 lb, 750 F	400 lb, 670 F	200 lb, sat.	5,150 kw
1200 lb, 750 F	400 lb, 518 F	200 lb, sat.	13,750 kw
2400 lb, 1000 F	400 lb, 618 F	200 lb, sat.	24,050 kw
125 lb mercury	28 in. hg vacuum to 400 lb steam	200 lb, 625 F	42,200 kw

[a] Pressures in lb per sq in. gage.

Therefore, it may be concluded that the present capacity installed in industrial plants is by no means a measure of what might justifiably be installed if an outlet were given for surplus energy, if full economic advantage were taken of technical development as shown in Table 1, if industrial management were educated in the economics of power generation, and if the utilities would accept the industrial plant as a possible source of cheap energy. It is obvious that these new conditions would result in a large increase in industrial capacity, mostly available for generating surplus energy. With industrial capacity now 28 per cent of utility capacity, it is equally obvious that any large increase in industrial capacity is of such magnitude as to satisfy the nation's demand curve for some considerable future period and leads us to the startling conclusion that the larger part of future electrical generating capacity should very probably be installed in or near industrial plants rather than in condensing-steam or hydro central stations. The superior efficiency of industrial "back-pressure" generation and its economic justification are well known to engineers and are shown elsewhere in this paper.

The public-utility systems are generally interconnected into a few great regional power pools, giving them the advantage of emergency supply, diversity, and reduction in spare equipment. Very few of the industrial generating plants are so interconnected either with each other or with the regional system. Many of the industrial plants generate electrical energy and utilize the exhaust heat from the turbine resulting

[1] Industrial Engineer, E. I. du Pont de Nemours & Co., Inc. Mem. A.S.M.E.

[2] Numbers in parentheses refer to bibliography at end of paper.

Contributed by the Power Division and presented at the Annual Meeting, New York, N. Y., December 4 to 8, 1933, of The American Society of Mechanical Engineers.

in a production of electrical energy with much higher thermal efficiency (80 per cent) than can be obtained in utility steam stations (25 to 30 per cent). The seasonal heating load of many industrial plants enables them to produce a surplus of electrical energy above the plant requirement and at very low cost during the peak of the heating season, which is approximately coincident with the load peak on the utility systems.

Alfred W. Fox works out a specific case (6) for providing the top 20,000 kw of an actual public-utility load-duration curve which contained 867,000 kwhr. If a new central station is provided, the annual costs are $262,000 for a peak load steam plant, $229,000 for a base-load steam plant, $255,000 for a hydraulic peak-load plant, and $257,000 for a steam-accumulator plant. An industrial plant having or needing the boiler capacity can provide the 20,000 kw in generating capacity and the energy at an annual cost of $171,000. This is an annual saving of $58,000. All costs are total, including fixed and operating charges. Mr. Fox concludes, "the figures used above may be open to question. I believe they are sufficiently accurate for a discussion of this nature and are moreover so variable as to require special attention and estimate on each particular problem. When times become normal, the peak-load problem of the public utility will again assume its previous importance, and I believe that solving the problem in conjunction with one of surplus power can mean a great saving to the utility and a source of additional profit to the industrial plant."

Many industrial power engineers believe the general refusal of the utilities to buy their available surplus energy is unsound national economics, unfair competition, and shortsighted policy. Guy B. Randall (7) also champions this opinion. They feel that such purchase or some interchange or other cooperative agreement will economically justify the installation of a great many more industrial power plants with a reduction in their own and the nation's power bills. These industrial engineers point out that most hydro stations and a great many utility steam stations are necessarily located remotely from the load center, requiring expensive, elaborate, and hazardous transmission systems which contribute to the result that the delivered cost of electricity to the ultimate consumer is from two to twenty times the cost at the generating station. (This spread should not irritate industrial plant engineers who pay two-dollar freight on twenty-cent coal, but should be accepted as economic fact.) A great many of the industrial plants are very near other consumers where industrial-plant surplus energy, lower in generating cost, could be delivered with small transmission loss to their neighbors if the utility transmission system were opened to the industrials.

The advantage of interconnection and other advantages of interchange with industrial plants have been ably pointed out by B. F. Wood (8). W. F. Ryan, a thorough student of this subject, outlines the advantage of cooperation and other industrial opportunities in his paper (9). W. S. Monroe has emphasized the importance of by-product power generation and pointed out the necessity for cooperation between utility and industrial companies (10).

Utility companies generally refuse this industrial-plant energy and other cooperative schemes for the following reasons (11):

(1) Possibility of having to face the charge of discrimination in cases where the utility chooses to make a working arrangement with one industrial and to deny it to another.

(2) Hazards to service presented by a number of small, isolated plants whose engineering and operating standard may be below the utility grade.

(3) Complications of supplying process steam non-electrical service to industrials.

(4) Financial hazards and disagreements potential in joint ownership and operation of utility and industrial plant equipment.

(5) Danger of increasing industrial business to an unsafe volume in proportion to total business.

(6) Objection to committing utility funds to investment in power facilities in industrial plants of uncertain business continuity.

(7) Possibility that an industrial plant with excess capacity will attempt to sell this directly to users at a higher profit than the interchange rate permits.

(8) Variations in efficiency of industrial plants delivering by-product electricity as a function of blast or other process heat usage.

(9) Inflexibility of such by-product plants as compared with utility generating stations.

But at least one utility executive (12) recognized the importance of power interchange and its benefit to the whole community, pointing out that it is the industrial plant's payroll which supports the utility and it is the utility's service which improves living conditions for the industrial's workmen. Cooperation between the two, he concluded, has a broad economic and sociological foundation.

Much of the difficulty in reaching a cooperative agreement for the mutual sale or interchange of electrical energy between utility and industrial companies lies in the misunderstanding of the value of a unit of energy. The value varies widely if it be "firm or dump," with the time of the day and year, and with the installed capacity of each party at the instant of generation. W. B. Skinkle has admirably and thoroughly expounded the fundamental principles in his papers on this subject (13, 14, 15). (These three papers are recommended to every engineer contemplating or negotiating a cooperative power contract.) Especially pertinent to the subject of this paper are Figs. 1 and 2 reproduced from Mr. Skinkle's discussion (13). Fig. 1 illustrates how the large generating units of a public-utility system increase capacity in steps, making the capacity growth very unlike the more uniform growth of the load curve. Fig. 2 illustrates how industrials and utilities may both delay investment and avoid installations of capacity far beyond requirement by a mutual and cooperative exchange of power. These curves refer principally to large-capacity industrial installations. It would be interesting to see the result if some utility system endeavored to provide for the gradual growth of its load by an equally gradual utilization of surplus power from industrial plants. The inspiration for such an attempt must come from the management or engineering groups of the utility company. At present, contact between utility and industrial is usually made by the power-sales division of the utility which, naturally enough, is only interested in selling energy and is not interested in the economic or engineering aspects of the power problem as a whole.

We hear much, especially from political sources, of the undeveloped hydro energy available in this country. Undeveloped hydro becomes more and more remote and it has already been pointed out that transmission costs now exceed energy-conversion cost. The public has heard very little in this country concerning the use of this great quantity of cheap industrial surplus electrical energy which is now available in the very heart of our consuming districts.

The power utility is given a monopoly on the assumption that it will serve the community more efficiently than any other means yet devised. Therefore, it is obligated to investigate sources and secure cheap energy, either by purchase or genera-

tion, and to distribute energy cheaply and efficiently. It is not unreasonable to ask these companies to purchase surplus industrial energy, if such purchase will benefit the community by fostering local industries and reducing the utility cost. Certainly this conception of the utility does not justify the intense and extravagant effort sometimes made to prevent industrial generation. Many individual utility companies are, in fact, only distributors, owning no active generating equipment and buying from affiliates. These distributors may well be asked to purchase industrial energy at a price commensurate with that they now pay.

This whole proposition is naturally so involved, technically and economically, that we can find a solution only through study and experiment made with greatest honesty and caution. So involved is each problem that the smoke-screen of confusion is ever at the disposal of partizans. So technical is each problem that all but the engineer are lost. Industrial managers are confused alike by equipment and power salesmen. This is a task for the most capable industrial and utility engineers.

While cooperation between utilities and industrial plants has no existence on a national scale, there are some isolated

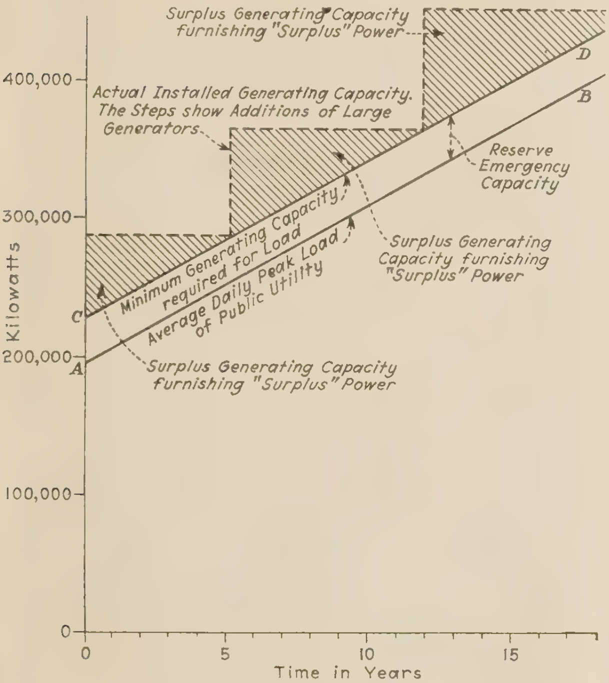


FIG. 1

instances, and it is the object of this paper to examine such cases as exist, review the contractual and physical arrangements, and evaluate the success, in the hope that this study may assist progress in cooperation between utility systems and industrial plants.

EXAMPLES OF COOPERATION ABROAD

In England, the Electricity Act of 1926 created a governing board to integrate public-utility generating systems. This Act provides for current to be fed into the "grid" from industrial plants and gives power to the Electricity Board to purchase surplus electricity in such cases. A British correspondent (16) stated in April, 1933, that at that moment there was no actual case from which he could obtain any particulars but gave as a reason that it was only recently that the grid has been put into actual operation and it is not yet complete. He believes that industrial cooperative schemes have been left over until the distribution of supply is more completely organized and the unification of frequencies achieved.

A prominent American engineer (17) states:

> The Belgium state has organized a corporation on which manufacturers, users, engineers, and the government are represented in the directorate to connect up all of the power plants, both utility and

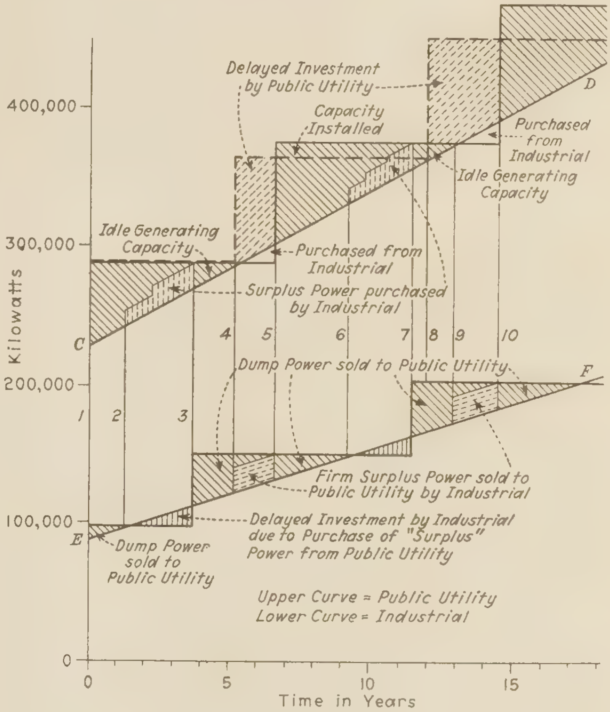


FIG. 2

> industrial, in the eastern half of Belgium. This corporation is known as the Union Générale Belge d'Électricité and has been running now for about five years. The arrangements have been most satisfactory, I understand, to all users and manufacturers, and the profits, while they have not been large, have been substantial and of sufficient amount to insure the continuation of the corporation. . . .
>
> The western part of Belgium is handled by Les Centrales des Flandres with headquarters at Ghent, while another public-service company operates Brussels and the surrounding territory. It is intended that in the end the whole of Belgium will be tied-in in one generating and operating company, but this will probably be sometime in the future.

While not of national importance, a regional cooperative arrangement of great interest and significance was consummated at Sydney, Nova Scotia. Here is a case where the power corporation and several industrial companies and a municipal lighting plant cooperated, with the approval of the Board of Public Utilities, with a result that has been satisfactory as regards service, economy, and earnings. Steel plant and mine operations are scheduled in such a way that the power corporation can provide necessary power at a minimum of cost. The effect of a proper rate schedule on power demand and usage at coal mines and steel plant has been extraordinary and has resulted in substantial economies for these industrial concerns. Refuse coals and coke breeze are used for generating electricity and domestic current usage tends to increase due to

reduced rates. K. H. Marsh (18) has provided data for 1929 in Table 2. He says:

TABLE 2 STATISTICS OF POWER GENERATION AT SYDNEY, N. S., 1929

Generating station	Kw installed	Frequency, cycles	Annual output, kwhr, in millions	Fuel
Steel Co., station No. 1	11,500	60	45	Blast-furnace gas, coke breeze, and coal
D. Coal Co., station No. 2	7,000	25	41	Slack coal, stoker-fired
D. Coal Co., station No. 3	4,000	25	15	Slack coal, stoker-fired
S. Coal Co., station No. 4	2,400	60	11	Slack coal, hand-fired
Utility Co., station No. 5	1,000	60	4	Slack coal, hand-fired
Municipal, station No. 6	400	60	1	Slack coal, hand-fired
Total........................			120	

The above plants [Table 2] are listed in order of efficiency. With more normal industrial activity all stations were overloaded at times.

Stations No. 2 and No. 3 (25 cycle) were tied together electrically.

Stations No. 1 and No. 5 exchanged stand-by service.

Stations No. 4 and No. 6 assisted each other at times.

Now in 1930, a power corporation was formed and put into operation a modern 7500-kw steam-electric generating plant, which was interconnected with Stations Nos. 1, 2, 3, 4, 5, and 6. A 25–60-cycle reversible frequency changer was installed, and a program of colliery electrification was completed. The power corporation leased Stations Nos. 1, 2, and 3. Stations Nos. 4, 5, and 6 were closed down.

The power corporation put into effect a schedule of rates approved by the Board of Public Utilities, and operates its very efficient modern station on base load, while Stations Nos. 1, 2, and 3 operate to suit the load from steel plant, coal mines, utility company, municipal lighting, as well as lighting for several small mining villages.

There are other instances in Canada where large industrial plants provide steam-electric stand-by service to promote good-will in communities where small hydro utilities could ill afford to provide their own steam stand-by. And the hydroelectric utility assists the industrial steam plants at certain times. There are cases where hydro installations with unused capacity sell electrical energy to industrials for use in steam boilers at little more than fuel cost, but, of course, on short-term contracts.

Examples in the United States—Parallel Operation

The simplest case of cooperation between utility and industrial in the generation of electrical energy occurs when the industrial secures part of its demand from the utility and operates its own generating equipment in parallel with the utility but does not feed back. So many installations of this kind exist in the United States that it may be called common practise, although a few utilities have earned the ill will of their customers by refusing to cooperate to this extent. This attitude is untenable, as can be proved by the entire success of the numerous existing installations. The utility in one large Eastern city states that it has twelve customers operating in parallel, the largest taking 6500 kw from the power company and the smallest 100 kw. All have contracts of three years' initial duration which continue from year to year with a 60-day cancelation clause. In none of these cases is there any pump-back of power into the utility lines and the power purchased is taken in each case under a standard form of contract.

There is an unusual case of parallel operation in an Eastern seaboard city where an existing industrial plant which generated all its own steam and electricity had an opportunity to sell steam to a new industrial located on adjoining property. The first industrial had sufficient installed capacity to supply its neighbor with both high- and low-pressure steam. The low-pressure steam could be extracted from one of the turbo-generators, but this extracted steam would only generate part of the neighbor's requirement. The local utility might possibly have blocked this sale of electricity because of existing laws, but generously cooperated and sold electrical energy to the first industrial for resale to the neighbor in accordance with the demand. All of the three parties profited. The utility gained by selling some energy and also succeeded in running its service lines into the plant of the first industrial which had never before been connected with the utility. The first industrial profited by the sale of steam and electricity without the necessity of increasing its installed capacity to meet the new load. The newly located industrial obtained steam and electricity at a cost lower than could have been obtained by building its own power plant and/or purchasing electricity from the utility. This arrangement has been in operation several years and has been entirely satisfactory to all of the three parties.

Many additional installations for parallel operation would be made economically attractive were it not for the additional financial burden imposed by the necessity for the industrial company to install spare generating equipment or pay a burdensome demand charge because of the periods when its one generator would be out of service. In a few instances, cooperatively minded utility companies have waived the demand charge on the grounds that the unusual demand was caused by an unavoidable breakdown. Modern central-station generating equipment has an availability better than 90 per cent and industrial turbo-generators without condensers probably have a higher availability. Industrial plants having normal week-end and annual inventory shut-downs can depend on emergency shut-downs occurring less frequently than yearly. Nevertheless, an industrial power engineer must conservatively include the maximum possible annual demand charge when preparing his project for the installation of a single turbo-generator and this prevents the authorization of many.

Utilities defend this high demand charge by maintaining that the business is unattractive and that generating and transmission capacity must be provided for the ultimate unavoidable breakdown. This contention is, undoubtedly, sound when considering a single installation or an isolated industrial at the end of a long transmission line, but if industrials which are located within a reasonable distance of each other were permitted to feed back their surplus energy into the utility system, the statistical effect, diversity, load factor, etc., would probably result in placing no additional burden on the utility's generating equipment by infrequent individual breakdowns and would require but very little additional transmission capacity.

An example of prohibitive demand charge existed in an industrial plant which generated all its energy but had a public-utility connection of some 300 kw demand for use in starting a cold plant after a total shut-down. The demand charge included some energy which was completely used. After two years' experience, the industrial secured a handsome return on an investment which was made for the installation of a 300-kw gasoline set. The service connection from the utility was discontinued.

A large utility which has numerous customers in parallel operation but none feeding back states that its company policy is an exceedingly broad one in dealing with special conditions and if, at a future time, conditions might arise wherein it would be advisable and profitable to both the customer and

the company to draw up a form of contract wherein any power would flow both ways, it is sure the company would give this serious consideration.

Industrials Which Sell Energy to Utilities

This subject is so shrouded in secrecy that no quantitative data can be secured or given. The issue of a magazine (19) devoted to this subject lists the following:

(1) Northern Paper Mills at Green Bay, Wis., developed two hydro sites with capacity over its requirement for sale to the Wisconsin-Michigan Power Co.

(2) Newton Falls Paper Company sells surplus hydro to Northern New York Utilities.

(3) The Wauregan Mills, Wauregan, Conn., sells surplus hydro up to 1000 kw and purchases power deficiency up to 300 kw.

(4) North American Cement Corporation, Security, Md., generates from waste heat and sells to the Potomac-Edison Co.

(5) The Colorado Portland Cement Company, Boettcher, Col., sells surplus electricity generated from waste heat to the local utility.

(6) The Manitowoc Plant of Medusa Portland Cement Company interchanges power with the Wisconsin Public Service Company, using waste heat to generate surplus energy.

(7) A woodworking plant in New Hampshire uses refuse to generate surplus energy for sale to the Twin States Gas and Electric Co.

(8) The Commerce Royalty and Mining Company, Cardin, Okla., operates a Diesel plant which supplies 18 lead and zinc mines, also the Northeast Oklahoma Railway in the city of Miami.

(9) The Sapphire Cotton Mills, Brevord, N. C., sells energy over the week-end to the local utility.

(10) The Fairbanks-Morse test floor sells surplus energy to the local utility.

(11) The University of Michigan sells surplus energy to the Detroit Edison Company during the heating season and purchases in summer.

(12) In Pittsfield, Mass., the electric company buys surplus energy from a large textile and dye works and sells stand-by.

(13) The Twin City Plant of the Ford Motor Company operates a hydro station which was built under the government requirement that all available hydro be generated. The surplus energy is sold to Northern States Power Company. The government gets free power for lock operation.

An interesting aspect of the last case quoted is the governmental requirement that surplus available energy be diverted into useful channels.

An industrial plant in Virginia generates all its own power and sells power to the utility for use in two near-by industrial plants during times of utility power failure. This cooperation by the industrial plant prevented the utility from losing two customers who would otherwise have built their own plants to secure continuity of service.

The Eli Lilly Company at its Indianapolis Laboratories purchases steam from the Indianapolis Power and Light Company, generates electricity with this steam, and sells the electricity to the power company. The electrical demands of the Eli Lilly Company are satisfied from the lines of the power company (20).

The Crocker-Burbank Company, of Fitchburg, Mass., sells surplus by-product power to the local utility (21).

A large motor company believed in 1931 that its power-plant loads had dropped to the point where it would be advantageous to purchase some current on week-ends and holidays and, accordingly, entered into an interchange agreement with the local electric company. This contract carries no demand charge and calls for an interchange of energy at a straight energy charge. Neither party guarantees to furnish the other power at any particular time and each party is the sole judge of its ability to serve. While this rate is classed as an interchange rate, the electric company has never permitted the motor company to deliver any power to it under the terms of the contract and in effect it is a straight energy contract without any demand charge. The contract may be classed as a failure, and one of the industrial company's officials states, "It has been my experience that there is not sufficient genuine cooperation between the utility and the industrial to result in the most advantageous mutual arrangements. The industrial plant is too often viewed as a competitor of the utility which the utility must endeavor to eliminate. This attitude is sure to interfere with entering into those contractual relations which would contribute most to the benefit of both parties."

For some years prior to the construction of its new central station, an Eastern utility bought energy from a large industrial which was so located on the utility's system that it could supply energy to great advantage during peak loads and when transmission troubles occurred. This was a straight sale of firm power subject to the call of the utility's dispatcher. This is an example of the utility's using available industrial capacity as exhibited in Fig. 2.

A utility has an interconnection with a large industrial company for the exchange of electric power. The interconnection consists of two banks of transformers rated at 30,000 kva each. Both banks are owned by the utility but the industrial is billed for the rental of the second bank. There is no formal contract covering the exchange of power. A letter, accepted by both parties, fixes the charge per kilowatthour of net exchange. There is, ordinarily, no such net exchange. During the reconstruction of the industrial's power house, a considerable supply of energy went to the industrial at a fixed price. On occasion, during tests, etc., the industrial has returned power to the utility but at a special rate much lower than fixed in the letter. Both parties stand ready to pick up loads in the event of an emergency and such an emergency has occurred two or three times. The utility states that the interconnection has been most useful. The arrangement may be terminated at any time by mutual agreement.

An industrial in an Eastern city has an installed capacity of 1250 kw with a day load steadily over 1000 kw and with occasional 1300-kw peaks. The plant is connected with the utility, and more than ten years ago made a cooperative agreement for exchange at $3^1/_2$ cents per kwhr and without demand charge. The exchange of power was nearly even and considered fair by both concerns. This agreement survived one change in ownership of the utility. After a larger holding company had taken over the local utility, it made many different propositions for supplying all the industrial's energy, but none was found acceptable. Two years ago the utility reduced the exchange rate to $1^1/_2$ cents and stopped taking energy from the industrial. One year ago the utility abrogated the exchange rate and put the industrial under a standard service classification. This increased the industrial's rate to 5.3 cents per kwhr. The industrial complains because its demand charge is figured from the maximum setting of its transformer switch. This, it feels, is unfair, and if not changed will force the industrial to build its own stand-by. Its own service had always been dependable. This switch must be set well above the actual demand because when set close to the

demand the industrial lost its load several times while running in parallel with the utility. The industrial's engineer states: "During the winter months when exhaust steam is needed, operation is such that the utility cannot expect to compete, but during the summer months when our loads are so high that we waste exhaust steam it is just too bad that the power company cannot compete with such methods."

Large-Scale Operations

Although utility companies have been reluctant to make cooperative agreements with smaller industrial plants, several large-scale operations exist in the United States where advantage has been taken of industrial waste heat and fuel or of industrial demand for large quantities of steam; thus giving opportunity for the cheap generation of electrical energy.

The Deepwater Station, located on the New Jersey side of the Delaware River some 30 miles below Philadelphia, is an outstanding example and has been adequately described in the technical press (22). This 1200-lb central station houses two condensing turbo-generators, each owned by a different utility, and also contains one turbo-generator which exhausts to evaporators. The evaporator vapor is delivered in quantity up to 400,000 lb per hr to an adjacent industrial plant. This is strictly a cooperative venture, although the industrial has no capital invested in the station. The industrial was about to build its own high-pressure plant when the utility contemplated a new station in the neighborhood, and one plant was built instead of two in the expectation of realizing the benefits which naturally accrue to a single large-scale operation. The station has been in service approximately three years and the entire operation has been successful. The contractual success is almost entirely due to the spirit of cooperation with which each party has settled unforeseen contingencies as they arose. Although the contract covered many pages and took upward of six months' careful negotiation to complete, it, nevertheless, did not foresee all possibilities, and if a spirit of cooperation had not existed among all contracting parties, ultimate failure might have occurred. Advantages to the utility have been a larger-scale operation and a high boiler load factor with consequent economies. The industrial has secured the benefit of skilled and efficient power-plant operation without burdening management with the responsibility. The disadvantages to the industrial were: First, the much longer construction period with consequent delay in achieving the economy of high-pressure operation. Second, there is not the flexibility in meeting changes in conditions which would exist if the industrial could operate entirely within its own organization and through its own procedure. The author is not in a position to state the disadvantages to the utility.

In 1929 the growth of load on a Southern utility system had reached the point where it was apparent that additional power supply facilities would be necessary. The ideal location for additional capacity was at the eastern terminus of the system which, as it so happened, was the location of an oil refinery. The refinery was planning extensions. A large generating station (technically not a utility) was built adjacent to the refinery. This station planned to supply the refinery with a maximum of 840,000 lb of steam per hr and 14,000 kw. The oil company could have built its own power plant and generated the electrical requirement with about 400 lb boiler pressure. By building for 625 lb pressure, a large surplus of electricity could be generated and is sold to the local utility. The refinery supplies several kinds of liquid refinery waste to be used as fuel in the power plant. Petroleum coke is delivered in railroad cars. Both parties had many vital interests to protect. The oil company was anxious to get the very best possible price for its non-merchantable but burnable waste fuels and to assure itself a continuity of service. The steam company needed guarantees for its investment and assurance of continued business, a very definite relation between the price at which it had to sell steam and electricity and the cost of fuel, and the ability to convert its plant to a normal type of condensing station should the contract with the oil company ever be terminated. As the situation developed, it became apparent that this contract could only be made on some mutual basis. Since the plant went into operation, an additional boiler has been installed to permit the sale of additional steam up to a total of about 1,000,000 lb per hr. The company which operates the plant is not a utility. It confines all its operations to its own property and its customers come to it with their pipe lines and electrical connections. It is so located that it is in a position to serve other customers at equitable rates, preferably those with needs for both steam and electricity. At present the entire requirements of the oil company and of one utility are well cared for, and the surplus energy is utilized by another utility.

A technical publication (22) states that the Iowa Railway and Light Corporation and the Quaker Oats Company at Cedar Rapids have an arrangement whereby the utility generates steam for the industrial and uses the industrial's waste fuel, oat hulls.

The same publication (22) states that the Rochester Gas and Electric Company supplies steam to several industrial plants and also heating steam to the business section and has 12,000 kw installed in non-condensing units.

Regional energy coordination in the Chicago district developed a unique cooperative arrangement between steel plants and electrical and gas utilities as described by A. H. Dyckerhoff (23). A very careful, extensive, and thorough survey of steel mills under all load conditions indicated that a saving of from $0.43 to $1.36 per ton of steel could be effected by selling coke-oven gas and purchasing electricity. This startling conclusion displaced the previously held opinion that steel mills should use all their available heat for metallurgical and power-generation purposes. An exchange of energy between steel plants and gas utilities has been worked out in the region of Chicago, linking six basic steel plants with electrical and gas utilities, resulting in purchasing electrical energy, selling coke-oven gas, and using blast-furnace gas for heating rather than for power generation.

The General Electric Company is building a mercury-vapor plant at Schenectady (5). Additional steam supply was needed and the New York Power and Light Corporation desired additional electric generating capacity, it being agreed that a steam plant erected at or near the Schenectady works could and would economically supply both. The General Electric Company constructed the plant on its own property, placed it strategically for steam distribution, and is leasing it to the power corporation which, in turn, operates and maintains the plant. The steam delivered to the Schenectady works at 225 lb pressure will amount to 630,000 lb per hr. The industrial provided the capital and constructed the plant, and the utility leases the plant on the basis of the fixed charges on the actual investment as a yearly rental. The utility admits that a plant having a capacity of 26,000 kw has for it a certain value per kilowatt of capacity, and the fixed charges on such investment are credited to the industrial. This amount is less than the rental, because the actual cost of the plant provided not only for the production of 26,000 kw, but 650,000 lb of steam also. The utility also allows a credit for each kilowatthour produced by the plant, all of which

goes into its system. This credit is based on the prevailing costs of producing power with modern plants supplying its system, taking into account the fact that the utility must always accept the power produced according to the steam demand, regardless of the hour of the day or the season of the year. The utility sells all the power that the industrial demands at scheduled rates, regardless of this particular agreement; and the excess cost covering the rental, operation, and maintenance and the fuel over and above the two credits allowed the industrial is charged to the industrial as its cost of steam. The agreement between the two companies covering operation is in effect for five years; thereafter continuing from year to year unless terminated by either party on one year's written notice.

Conclusion

Modern technical developments in higher steam pressures and mercury-vapor cycles make available more and more surplus electrical energy from industrial steam flow, and this technical development favors the generation of electricity in connection with industrial processes.

The steam flow to industrial plants is of such magnitude and the industrial plants are so located that the larger part of future electrical generating capacity should very probably be installed in or near these industries rather than in new condensing steam or hydro central stations.

Cooperation between public utilities and industrial plants in the generation of steam and electrical energy will reduce generating cost and the investment in generating equipment, thus ultimately reducing the nation's power bill and resulting in the still wider dissemination and use of electrical energy, which is the basis of our industrial civilization.

An unsound economic condition in power generation is maintained by the utilities' competitive sales campaign.

Industrial management must be educated in the apparent paradox that small-scale "back-pressure" power generation is more efficient than the "quantity production" in condensing central stations.

A spirit of cooperation must be fostered by public-utility executives and engineers if industrial engineering antagonism is to be avoided and public relations improved.

A detailed survey of American conditions will probably prove, and the success of the Union Générale Belge d'Electricité indicates, that a program of cooperation will be successful.

BIBLIOGRAPHY

1 Supplement to *Electrical World*, May 6, 1933.
2 Fifteenth Census of U. S., Manufacturers, 1929, vol. 1, p. 112.
3 Fifteenth Census of U. S., Mines and Quarries, 1929, vol. 1, p. 16.
4 Discussion of "Higher Steam Pressures and Temperatures," Winter Convention, A.I.E.E., January, 1933.
5 "Coordinated Production of Industrial Steam and Utility Power," by A. R. Smith, *General Electric Review*, July, 1933.
6 "Surplus Power—Availability, Cost, and Economic Disposal," by Alfred W. Fox, *Power Plant Engineering*, July, 1933, p. 312.
7 "The Pooling of Power," by Guy B. Randall, *Power Plant Engineering*, June 1, 1932.
8 "Engineering Aspects of Interchange of Power With Industrial Plants," by B. F. Wood, Trans. A.S.M.E., 1931, FSP-53-26b.
9 "Combined Heat and Power Supply in Industrial Plants," by W. F. Ryan, Trans. A.S.M.E., 1931, FSP-53-26a.
10 "Tendencies in Future Power Station Developments," an interview with W. S. Monroe, *Power Plant Engineering*, January, 1933.
11 *Electrical World*, May 30, 1931, p. 1005.
12 "Industrial Power Interchange," an interview with T. O. Kennedy, vice-president and general manager, Ohio Public Service Co., Cleveland, Ohio, *Electrical World*, March 17, 1928.
13 "Discussion of Papers on Interconnection Between Public Utility and Large Industrials and the Interchange of Power Between the Two Systems," by W. B. Skinkle, engineer, Pittsburgh District Power Committee, Subsidiary Companies of U. S. Steel Corp., *Iron and Steel Eng.*, May, 1931.
14 "Cost Sheets and Their Relation to Engineering Economics," by W. B. Skinkle. Engineers' Society of Western Pennsylvania.
15 "Purchasing Public Utility Power for Industrial Use," by W. B. Skinkle. Engineers' Society of Western Pennsylvania.
16 F. W. Gardner, C.E., Turbine Department, C. A. Parsons & Co., Ltd., Newcastle-on-Tyne, 6.
17 Geo. A. Orrok, consulting engineer, New York, N. Y.
18 K. H. Marsh, C.E., Dominion Steel & Coal Corp., Ltd., Sydney, Nova Scotia.
19 *Power*, May 27, 1930.
20 "Plant and Utility Exchange Steam and Power," *Heating, Piping, and Air Conditioning*, May, 1932.
21 "Crocker-Burbank Central Steam Plant Extension," *Heat Engineering* (Foster-Wheeler Corp.), May, 1933.
22 "Utilities That Supply Steam," *Power*, May 27, 1930.
23 Series of four articles, "Regional Energy Coordination," by A. H. Dyckerhoff, *Electrical World*, Feb. 27, Mar. 5, 12, and 19, 1932.

Discussion

J. H. Cather[3] wrote: As Mr. Harkins points out, extracting more electric power from steam required for industrial purposes would seem to be a field with considerable future possibilities.

The largest steam-electric power plant of the Eastman Kodak Co. has a minimum summer steam load which averages about 66 per cent of the maximum winter load. Careful investigations by the engineers of the local utility and by this company's engineers were made recently regarding the possibilities of extracting a constant amount of surplus power from the minimum steam load.

A new 125-lb mercury plant and also an alternate 1400-lb steam plant were designed—these plants to supply approximately 300,000 lb of steam per hr to present 260-lb steam turbines.

The maximum the utility could afford to pay for this firm power was naturally the cost at which it could produce this power in a new high-pressure condensing plant of its own. The final report, written in July, 1932, commenting on this investigation, concludes "that the installation cost or the price to be paid per kilowatthour must change before the scheme would be attractive." It seems probable that future developments will make installations such as these investigated economical for conditions such as ours. Mercury boilers for 125 lb will probably reach a more commercial basis after experience with the two plants now going into operation.

The generating plant of the Eastman Kodak Co. has, for a number of years, operated with no unusual difficulties on an almost exact steam-electric balance, using non-condensing turbines and engines. This is made possible by the sale of surplus or "dump" power to the local utility in the colder portions of the year and the purchase from it of part of the required power at other times.

A. G. Christie[4] wrote: The idea of interchanging steam and electric power between utilities and industries seems to be making headway very slowly in this country. Mr. Harkins points out a number of reasons why utilities generally refuse to purchase the surplus power of industries. He might have added another reason; the desire of the utilities to dominate and monopolize all power generation and distribution. The Government yardstick for electrical rates announced by the Tennessee Valley Authority may cause utilities to look more

[3] Engineer in Charge of Power, Kodak Park Plant of Eastman Kodak Co., Rochester, N. Y. Mem. A.S.M.E.

[4] Professor of Mechanical Engineering, The Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

carefully into every possible source of cheap power in order to enable them to lower rates, and this may lead to further interchange agreements.

We may possibly be forced to copy the Belgian idea with a regional committee under Government authority to coordinate all sources of heat and electrical energy for joint benefits to all concerned. This is not at all unlikely under the present socialistic trends of our Government.

Mr. Harkins comes close to the facts when he places the blame for lack of cooperation upon the influence of the power-sales departments of the utilities in determining policies toward the industries. Were these matters left to the production and distribution engineers, agreements could be effected much more readily.

The examples quoted by Mr. Harkins are helpful as indicating the nature of agreements now in effect. There seems to be no standardization of plan. Possibly a little more study on the part of the utility executives would lead to a more systematic approach to the problem. As I pointed out in my paper[5] before the Industrial Power Group last year, there must exist a spirit of mutual confidence on the part of both utility and industrial plant for any interchange of power to be mutually satisfactory. As long as one attempts to take advantage of the other, no lasting or satisfactory agreement can be consummated.

Much can be gained from more whole-hearted attempts to find a basis for interchange. This timely paper will add encouragement to efforts in this direction.

E. D. Dreyfus[6] wrote: Mr. Harkins has set forth many interesting statements and references that demand careful thought. Economy should always be the byword with the engineer in the matter of investments as well as with materials and forces. "Material economy" may be encompassed with a reasonable degree of definiteness, while "investment economy" is too frequently influenced by many intangible and often unforeseen factors such that the ultimate results for the long pull may fall considerably short of expectations. Fortunately, in an advancing engineering and developmental business period, errors in "economic" judgment are sometimes overshadowed by the profits of associated operations and by surrounding improvements. During a stationary period or a business depression, such errors, as are all too well known from our recent lesson, are likely to prove fatal. With this premise it might be well to view seriously what may be made of a utility-industrial interconnection and coordination of power-producing facilities to mutual advantage. As interestingly brought out by Mr. Harkins, there is apparent saving under such a program, particularly where by-product power of one form or another may be involved. Therefore, both utility and industry owe it to the community in which they operate to make the most of the opportunity to improve the region's economic position.

Many good examples have been cited as evidence of the fact that interchanges of steam and electric power have been successful in some localities. The question naturally follows: Why has the practise not been more universal in the past? Possibly we all may agree on one factor as responsible for the limited progress made in this direction and that is the element of *risk* involved.

Every planner is duty-bound to safeguard adequately the capital entrusted to his care; figuratively, a factor of safety must be introduced in relatively the same conservative way as is done in dealing with fiber stresses. No one would dare approach the elastic limit in the latter case, but this may be done in the case of an investment unless restraint is placed upon those sponsoring the development. The engineer has gone a long way in mastering physical problems and it is now incumbent upon him to look to the financial side with the same degree of perspicacity and conservatism—an economic error being as monumental as a structural failure. By so doing, the stigma that the banker placed on the engineers decades ago to the effect that financial backing for their projects would only be forthcoming provided the development would still pay with the actual cost assumed to be twice the estimate and the earning power reduced by one-half, will no longer be justified. Therefore, the approach to the problem of joint utility-industrial power interchange must be made with such foresight as may be commanded.

Those of us who have attended the meetings of this Society during the past quarter of a century have witnessed some startling changes; the coming and going of the gas engine; the low-pressure-turbine innovation and its comparative dying-out; and the like; and have listened with deep interest to discussions about the change in "style" of power-plant equipment over the years. This may sound fanciful but is nevertheless real as borne out by the mute evidence in the machinery graveyards in many quarters. Furthermore, there is no guarantee today that we have reached anything like a stationary position. Some new discovery in the matter of the heat cycle; chemical process using the "cold" in place of the "heated" state; substitution of electricity for fuels in metallurgical reactions and treatment; the possibility of a different kind of heating and ventilating system; and other industrial applications may arise to supersede the type we now know, thus destroying the economic balance of an inter-industry development which would have been profitable under the present circumstances. While it is not fear that should rule, but in ordinary investment as in ordinary dangers, "discretion is the better part of valor."

If we look further into the fundamental differences in the general character of the utility and the industry, we find that the utility has been declared by law to be "affected by the public interest" and therefore has been brought under the police powers of the state and closely regulated. The industrial establishment is still pretty much of a free lance although temporarily NRA laws now exert some slight restraining influence.

With the utility, the earning power is limited and turnover of capital is slow. The rates charged for service embrace only a very moderate depreciation accrual on the basis of virtually continuous life. On the other hand, the industry is only limited in its profit realization by whatever competition it experiences. In good times the industrial may earn sufficient surplus after a fair yield on its investment to write off the cost of the property in a comparatively few years. Consequently, the accrual policies of utility and an industrial plant necessarily vary widely.

I sometimes wonder when this subject of utility-industrial power interchange is discussed whether it is fully borne in mind that, as far as the utility is concerned, it is a 100 per cent business-producing investment, whereas with the industry the power-generating facilities represent only a small fraction of their investment in total plant for manufacturing purposes. Consequently, any economic error that might be made in either case would be of a magnitude with the utility many times that of the industry.

Another feature deserving close attention is that changes in the points of delivery to or from the power system may have a disturbing effect upon the investment economy as a whole if the use of existing facilities is modified to an appreciable extent through changes of manufacturing methods or processes, and thereby more or less power for interchange.

[5] "Surplus Power From Industrial Plants," by A. G. Christie. Mechanical Engineering, November, 1932, pp. 771 to 774.

[6] Engineer, Pittsburgh, Pa. Mem. A.S.M.E.

It is also to be remembered that the utility must pass on to its customers the benefits of the savings realizable through the interchange of power supply under discussion. While profit may be the incentive to the industry, duty must be largely the impelling reason for the utility to enter an arrangement of this kind. It may be safely stated that the utility has been giving serious consideration to the interconnection possibility, but in weighing all factors it has been forced to the conclusion that undue risk must be reasonably avoided.

The industry should by right be entitled to an outlet for surplus by-product power it may be able to generate and the utility should receive and market the power provided it does not, by so doing, impose any disadvantages upon its dependent customers and upon its owners.

In the limited time for discussion I will attempt to outline very briefly (as one individual way of attack) one plan that might stimulate proper utilization of industry's waste power. To view the problem adequately with the object of establishing equitable relationships, a set of basic conditions are briefly presented, as follows:

(1) It is presupposed that normally where no by-product power obtains, the utility may supply the power needs of the industry and thus minimize investment expenditures for the district.

(2) Where by-product power of one kind or another is available, the utility would install the necessary prime mover, cooperating with the engineers of the industry.

(3) The industry would finance the installation and the utility would refund the cost on a basis of credits according to the power developed—the rate to be based upon equivalent cost to the utility for like power, taking into account the question of necessary reserve to be allowed for and reasonable compensation for the intermediary service provided.

(4) Title would pass to the utility after credits had equaled the installation costs and the utility would be the sole agency for the power supply of the district and therefore in position to establish the lowest power cost for the district. Proper terms, minimum operation, and other factors must be prescribed to insure achievement of the plan. In event the industry underwent a radical change in its manufacturing method, the loss to the utility would be a minimum as it would come into possession of the generating equipment and recover partly on their outlay made through credits against revenues.

In the foregoing, I have merely tried to stress that there must be a mutual financial responsibility in the plan—with risk factor duly weighted—and further to give some indication of how such an idea may be carried out in practise. There have been similar methods employed in somewhat like situations heretofore which have been worked satisfactorily and I am confident they may be successfully applied to interchange problems.

Finally, I wish to add the observation that the careful reasoning on these investment matters will constitute as progressive a move as designing new types and installations that may not have real economic merit when all factors—time, business, and manufacturing variables, and specific operating characteristics—have been completely tested. The A.S.M.E. is doing a splendid piece of work in the contributions it has encouraged and published, which are intended to provide an understanding (which should aid in the solution) of our economic problems.

A. H. Dyckerhoff[7] wrote: Beyond doubt, there is a great desirability of such cooperation between utilities and industrials under proper economic conditions and I feel safe in saying that the utilities are more desirous of cooperating than *most* industrials, notwithstanding the different view expressed in the paper under discussion. In this statement I am guided by my work for an industrial and for a group of larger utilities having close contacts with numerous large industrials. I cannot agree with the author of the paper when he states that "the power-sales division of the utility is only interested in selling energy and is not interested in the economic or engineering aspects of the power problem as a whole" or that "sometimes extravagant effort is made to prevent industrial generation," or that "an unsound economic condition in power generation is maintained by the utilities' competitive sales campaign."

Mr. Harkins shows two diagrams evolved by W. B. Skinkle, suggesting coordinated increase of generating capacity by the utility and the industrial for the purpose of avoiding generating capacity beyond requirements. This procedure is theoretically interesting, but is applicable in very few instances, because of the vast difference of capacity of generators required by utilities and industrials.

Another stumbling block in the road of cooperation is the very frequent extravagant idea expressed by engineers of industrials as to the value of dump or surplus electric energy available by their plants. It is not kept sufficiently clearly in mind that a utility is obliged to give service at all times on demand. Therefore, it must have sufficient generating capacity at its disposal and under its control to meet such requirements immediately. For this reason any dump energy to be delivered by the industrial can have fuel value only as determined by the most efficient power plant of the utility. If we assume, for instance, that an energy of 13,500 Btu *net* is required per kilowatthour by large generating units at, say, 40 per cent capacity factor, and the cost of coal burned is 1.7 cents per therm, the value of the dump energy is but about 0.23 cent per kwhr. From this value certain deductions must be made for losses and fixed charges for investment, if the lines of the utility are not available within the immediate proximity of the industrial plant. If proper allowance is made for such items and if consideration is given to the approximate price of 0.4 to 0.5 cent per kwhr, which is expected by some industrial plant engineers, it is evident that such schemes are bound to collapse if the absorption of surplus electric energy of the industrial by the utility is the sole purpose of the interconnection of the utility and the industrial. However, if the industrial will purchase at least a fairly substantial block of electric energy from the utility, and wishes to feed back into the utility system surplus energy in proper proportion to the energy purchased at the approximate fuel value of the utility power station, a good economical foundation for cooperation would be established.

Likewise, difficulties arise frequently when it is intended to tie private plants having small capacity to large utility systems for lack of proper regulation, a low power factor of the industrial plant, proper capacity of circuit breakers, etc. To overcome these difficulties additional expenses must be incurred militating somewhat against the unidirectional flow of surplus energy from industrial to utility.

It should be kept in mind that, while the regulation by the Commerce or Railroad Commission applies mainly to the sale of electric energy at definite rates without discrimination, the utility must grant similar conditions of service to *all* industrial plants. Since these naturally show considerable different economic set-ups in the generation of energy, it is obvious that variations in set-up stand somewhat in the way of effecting the exchange of electric power between utilities and industrials.

Since several instances of cooperation abroad have been cited in the paper, it should be mentioned that overall utility practise in this country is somewhat further advanced than that abroad and also that the sale of energy per capita is considerably

[7] Engineer, Chicago, Ill.

higher. As a result, the electric rates are relatively lower than in Europe if we consider that the cost of equipment is 40 to 70 per cent higher in this country. The conclusion is that the natural flow of energy is from utility to industrial. It should also be kept in mind that the European and foreign plants, some of which have been cited in the paper, are relatively small and in many cases are possible because many European utilities are not subject to the rulings of commissions and are freer in negotiating power contracts as dictated by individual conditions.

Dual-purpose utility power plants occupy a distinctive position in the vast field of producers of energy in various forms and will be built wherever the economic and local conditions warrant. It cannot be construed as lack of cooperation on the part of utilities if they find themselves unable in times like the present to respond in every instance to a demand for steam and power in a certain locality. Unfortunately, little definite practical information of such dual-purpose power plants have been made available.

Lastly, it should be mentioned that energy in various gaseous forms must be considered in the interchange or buying and selling of energy. Long-distance natural-gas lines, replacement of rich gas by lean gas, use of mixed gases, availability of refinery gas, low off-peak gas rates, adjustable off-peak electric rates, all play important rôles in this adjustment, which has been going on during the last five to ten years. Judging by conditions in the Chicago district, the reproach made by the author is wholly unjustified. Such projects cannot be forced through as a general policy; each project must be considered individually and must stand on its own merits.

Alfred W. Fox[8] wrote: Mr. Harkins has presented an interesting résumé, pursuing his analysis to logical conclusions with which I am in full agreement.

Unfortunately, some of the public utilities maintain an "all or nothing" attitude, that is, they do their utmost to prevent the installation of a private plant, but if it is built, they will refuse to cooperate in an interchange of power and will not furnish stand-by service except at relatively exorbitant rates. Obviously, if the industry's low-pressure steam requirements are greatly in excess of the electrical, it is deprived of an additional source of profit from the sale of surplus energy.

In all fairness to the utility, however, such surplus energy, available only in small quantities and at odd moments, is worth only the saving in generating cost at the least efficient central station which happens to be on duty at the moment. The figure, consequently, would not be the same in the different utility systems and would vary in any one system with the load, but it may be taken roughly as 3.5 to 4.5 mills per kwhr.

Assuming that the steam and electric generating plant is already installed, the cost of producing such surplus energy is made up of the fixed charges on and the operation of the necessary substation and switching equipment to tie into the system. The additional fuel required may be neglected in most cases, since the advantage, for process purposes, of superheated steam from a reducing valve over dry saturated steam from a properly proportioned back-pressure or bleeder turbine is negligible in the average industrial plant. This cost must be deducted from the 3.5 to 4.5 mills given above to determine the true value to the utility or the net profit to the industry. It is apparent that unless large quantities of surplus energy are available there will not be a great amount of profit for either party.

The point which I should like to emphasize is that proposed industrial plants in a position to supply surplus energy could, at relatively slight expense, be converted to give firm power either under direct utility supervision and operation or subject to the call of the load dispatcher. Energy in this form is worth much more than 1 or 2 mills per kwhr; it is worth that plus the capacity value of the peak load which it is able to carry. This should be self-evident but a simple illustration may be of interest.

Table 1 of the paper presents interesting data, showing that an industry requiring up to 400,000 lb per hr of 200-lb steam can generate from 0 to 42,000 kw, depending on the type of plant selected. If the industry requires up to 5000 kw and if the steam and electric demands are fairly coincident, it might install a 400-lb 750-F boiler plant and back-pressure turbine which would take care of its own needs.

If, however, a market for surplus power existed, at slight additional expense, say, $7 or $8 per kw, a 1200-lb 750 F plant could be installed and would supply 13,750 kw, or 8750 kw additional. Assume that the local utility company has an installed capacity of 100,000 kw and is carrying a peak load of 93,000 kw. A year from now the load is expected to increase up to or beyond capacity and a new unit or plant will have to be added to the system. The cost of a new plant would probably be not less than $80 per kw, but the cost of adding capacity to the industrial plant should be about $40 per kw. With 15 per cent fixed charges, a net capacity value of $5.35 per kw or $46,875 should be credited to the industrial plant.

This materially enhances the value of the surplus energy. It may be argued that the industrial plant's maximum steam demand of 400,000 lb per hr might not coincide with the utility's peak-load periods and that only 2000 or 3000 kw might be available. But what is to prevent the generation of 400,000 lb of steam per hour during these relatively few hours per year and even venting the exhaust steam to the atmosphere if the installation of a low-pressure turbine could not be justified? If the plant were called on as often as 100 days a year with 50 hr of actual use, the waste would be less than $10,000.

It is in this respect of providing peak-load capacity that stations like Deepwater, Baton Rouge, and Schenectady are distinguished from the numerous smaller ones which furnish merely surplus energy. Undoubtedly many existing industrial power plants could provide the utilities with stand-by service which will be of value when loads again pick up.

As Mr. Harkins points out, industrial executives must be educated in the natural advantages for economic electrical generation possessed by their plants, and a spirit of cooperation must be developed by both parties to insure success. Perhaps many of these projects will never be developed until both parties are brought together by a disinterested third person—an engineer with the ability and patience to work out the many complex details which must arise.

C. F. Hirshfeld[9] wrote: When one discusses a paper on so controversial a subject as that treated by Mr. Harkins, there is always the danger that one may be accused of a partizan viewpoint. For this reason I think it well to start with certain remarks of a personal character.

I am employed by a well-known light and power company and for that reason may be assumed to have the utility viewpoint.

But the utility with which I am connected is widely known as an open-minded and progressive one and has, in fact, not only studied interconnection with industrials for many years but is actually operating with several such interconnections at the present time.

Further, as early as 1929 I presented at a national meeting of

[8] Consulting Engineer, Utility Consumers' Service, New York, N. Y. Jun. A.S.M.E.

[9] Chief of Research, Detroit Edison Company, Detroit, Mich. Mem. A.S.M.E.

light and power company executives a rather elaborate and comprehensive study of the possibilities, advantages, and limitations of such interconnections and have been identified with the discussion of the subject more or less ever since.

And finally, as a private consultant, I have handled, for both power companies and industrials, studies and negotiations in this field. I believe you will agree that, in spite of my utility connection, I should be able to view this problem in a manner at least approximately non-partizan.

I want to start my discussion by complimenting Mr. Harkins upon the very broad and impartial way in which he has treated the subject. He has endeavored to point out honestly and fearlessly both the good and the bad. He has criticized equally the mental inhibitions and ineptitudes of both parties to such agreements. He has, on the whole, endeavored to give an elder statesman's treatment of the subject and I believe he has succeeded very well indeed. Moreover, while doing this he has collected in one place and in easily readable form a mass of very valuable information.

But it must be noted that his treatment rests fundamentally on certain statistical facts, such as the relative capacities of central-station and industrial plants for the country as a whole, the increased electrical output obtainable with improved equipment in industrial plants, and the like. This is a valuable but also, on occasion, a dangerous method of analysis as is well illustrated in the field of by-product central steam heating.

For example, it has been shown many times by this method that power companies could do a very profitable central-heating business by generating electricity in non-condensing equipment and distributing the exhaust steam for heating purposes. And yet, those companies having the largest central-heating installations have resorted almost entirely to the direct generation of heating steam instead of the use of combination plants. And it should be noted that in some cases these companies actually started the business with combination plants. There is no overall and simple explanation of this phenomenon. Noncoincidence of heating and power loads and different characteristics of the two loads form parts of the explanation. The occurrence of electrical peaks at times of the year in which steam loads are close to minimum values is another part. The cheaper distribution system obtainable in a large area when high-pressure feeders are used in preference to low-pressure feeders is another. In fact, the problem is so complex that each case must be studied separately and on its individual characteristics.

The same sort of thing is true with respect to interconnection of industrial and central-station properties. There is no doubt that there are cases in which such interconnection is highly advantageous to both parties, but it would be wrong to argue from these that this must necessarily be true in all cases or in the great majority of cases.

The author correctly puts his finger on one of the great difficulties met in attempting to negotiate such interconnections when he refers to the misunderstanding of the value of a unit of energy. He might properly go further and state that this is only one of many difficulties which may be summed up either under the head of difference in viewpoint or difference in character of business. After all, each industrial establishment is run for the purposes of itself and not to supply by-product energy. In general, the by-product is not of sufficient value to justify its production in the absence of need for the principal product. And therein lies the great stumbling block in the way of many apparently possible interconnections.

The paper refers to the necessity of conducting negotiations through or with the full knowledge of the engineers of both parties in interest. He undoubtedly has in mind, though possibly unconsciously, the engineering staff of an industrial of the type he is connected with. However, if any such extent of cooperation as he envisages is to be brought about it will involve dealings with industrials of much smaller magnitude. Here one meets, in general, executives who know little or nothing about steam and power problems and operating engineers who have their reputations and their jobs to protect. The combination is well-nigh hopeless and such experience in this field as I am familiar with indicates that this combination probably presents more difficulties than any other single phase of this complicated problem.

The paper under discussion lays great stress upon the economic advantages of these interconnections from the national viewpoint. I think it correct to assume that the refinement of all arts and businesses which comes with age and with competition will automatically lead to more and more of these arrangements. But in every case they must be based upon business advantage to each of the parties to the agreement and not upon any altruistic motive such as the conserving of the national store of fuel or the improvement of national business.

In closing, I would like to draw attention to one aspect of this matter that the paper does not touch upon and which I have never seen referred to elsewhere in this connection. When a company undertakes to render public service it incurs certain legal obligations. Having placed itself in the position of a public utility it has, for instance, certain obligations with respect to the supply of that service to the public. I am an engineer and not a lawyer, but I suspect that if the interconnection of industrial plants to public-utility systems goes very far some industrial executive who has not had adequate legal advice will wake up some day to discover that his power plant is legally part of a public-utility system and must be run to the extent that public service dictates rather than as his private business demands. I know of at least one case that is somewhat similar to this and in which the court decided against the well-meaning industrial.

J. C. Hobbs[10] wrote: The total cost of producing service is less when industry and utility cooperate than when they operate independently. The saving in operating expense is then available for distribution between them in the proper ratio. If cooperation does not exist this saving is not accomplished and a preventable waste occurs.

A simple rule which has proved successful in individual inter-company cases is:

(1) Determine what action would be taken if the properties were unified. This is what is done in every case of detailed equipment design and it should be done in inter-department and inter-company problems. Utility engineers do not adopt motor drives for main auxiliaries because of the savings shown when figured on the basis of their standard rate schedules but rather on the actual station cost. Power-station design also incorporates the same heat-balance problems which the present subject covers.

(2) Determine an equitable distribution of the benefits derived from combination operation and adjust the costs to each accordingly.

In other words, many of our problems today are not engineering or financial problems but questions of policy which should be solved on a sound basis so as to take full advantage of the opportunities.

Unfortunately, the elements of such problems are not always as clear and as easily recognized as are the almost exact quanti-

[10] Superintendent of Power, Diamond Alkali Co., Painesville, Ohio. Mem. A.S.M.E.

ties found in steam and electrical calculations. Nevertheless, they represent dollars and should be so equated.

E. C. Hutchinson[11] wrote: Mr. Harkins has brought together and correlated an extremely interesting series of thoughts, facts, and figures appropriate to the title subject. Through the paper is a number of pertinent statements, any one of which may be developed easily into a small book. For this reason the paper is exceedingly stimulating to any one who will wish to give it serious thought.

There is no doubt that a predominant policy among public-utility companies heretofore has been to discourage the installation of industrial power by one means or another. There are, of course, some notable exceptions to this statement, but in the main it has been correct.

I make this statement in the past tense because I believe that there is rapidly coming into the minds of utility executives the newer concept that the economics of any power-service requirement for industry or elsewhere must ultimately prevail. Therefore, it is unwise for any utility to take a position in which its policies are assailable and subject to destruction by the pure logic of the circumstances.

Those utilities which have cooperated with industrial companies by exchanging power services, and even by extending steam services from utility to industry, are, to the best of my knowledge, well satisfied with the relationships they have developed. Some express frankly their satisfaction with the results and decry the attitude of other utilities which persist in the old viewpoint. There are, for instance, utilities which, while not denying the economic superiority of the Diesel engine under certain services, still flatly refuse to use one or have anything to do with oil engines, because they have been the instruments through which some of their most difficult competition has been developed. There are likewise other utilities which have hospitably taken the Diesel engine into the family circle because it is a willing and efficient worker and may as well be doing it for the utility as for any one else.

In discussing the cost of transmitting electricity, the author mentions that it costs from two to twenty times as much to distribute electricity as it does to generate it at the station. He then makes an interesting and not ordinarily thought-of comparison between the cost of producing a ton of coal and transporting it to the point of consumption. While the paper states a case in which the distribution cost was ten times the cost at the mine, it should be pointed out that there are many cases where it is fifteen times, or even more.

One is also reminded of the occasion in Germany during the World Power Conference of 1930 in which the American Ambassador was strenuously taken to task by Samuel Insull for a statement made in a speech criticizing the electrical industry for the large spread between the cost of producing electricity and the cost to consumer.

It will be well indeed to give constructive publicity to the thought that transmission costs for electricity are, after all, no greater proportionately than are numerous other distribution costs. Distribution costs will not increase if they are not economically justified. Moreover, they will be sure to decrease in the face of more efficient power generation in industrial plants.

Thus is seen definitely today the trend away from the blind purchase of utility power and the entrance into the question of "shall we purchase" or "shall we make" is a higher type of intelligence and a better grade of engineering than in any previous time. This, I believe, is going to have the effect of limiting the expansion of utility business, generally speaking, to those fields in which their service is economically superior to anything else. There are many such places and there are tremendous prospects for the growth of utilities. Such growth will, in my opinion, be enhanced and become effective in proportion to the willingness of the utilities to accept properly qualified isolated industrial plants into their network upon an equitable and mutually satisfactory plan for cooperative development and the interchange of steam and electric service.

[11] New York, N. Y. Mem. A.S.M.E.

K. M. Irwin[12] discussed the paper as follows: Mr. Harkins mentions the cooperation between the company by which I am employed and industrial concerns. I personally have spent much time with Mr. Harkins on one cooperative arrangement which is working out to the satisfaction of both parties. I am assuming, therefore, that this paper excludes "present company" and I want to assure him that my remarks do also.

The impression given by the statements and data on the first two pages is that the capacity and energy that might be obtained by increasing the pressure in industrial plants and expanding the steam through back-pressure turbines is usable and of value to utility companies and that it is only their "shortsighted policy" and "unfair competitive method" that prevent its purchase. The first statement of the conclusion also presupposes that the capacity obtained is firm and that the energy has a definite value.

In our experience, it has been difficult to find an industrial development where the excess capacity would be firm on the load curve. A definition of firm capacity is "capacity which will be, beyond question of doubt, available for use when needed." If the capacity is not firm, the utility cannot pay money for it. We are sorry that "many industrial power engineers believe that the general refusal of the utilities" to pay money for something that is of no value to them "is unsound national economics." I fear they mix "national economics" with what is best for their own particular firm. The surplus energy is worth, to the utility, something less than it would cost the utility to make it itself, less the transmission losses. In these days of interconnections between neighboring large companies, surplus power is, broadly speaking, a commodity of which there is a surplus and every fifth row should be plowed in.

It should not be forgotten that in taking surplus energy, great care must be exercised not to use up transmission and distribution capacity which is needed for the normal business, as savings on surplus power can hardly be large enough to carry additional investments.

A great deal of time and money has been spent by our company in making studies of concrete cases where it at first appeared possible to build a plant to supply a particular consumer or groups of two or three consumers electrical energy and steam. To date, only two cases have worked out to a solution which would be mutually profitable to both parties and would also safeguard them against the contingencies of load variations. One of these cases is the Deepwater arrangement, and the installation of the other has been delayed due to business conditions. This type of arrangement ties up a relatively large amount of capital to the load stability of one or possibly two or three customers.

Industrial plants have undergone radical changes in their steam and power requirements in the past. With business fluctuations, they may shut down for periods of time, change their products, change their process of manufacture, eliminate or add processes, or even go out of business. Tariff changes have

[12] Assistant to Vice-President, Philadelphia Electric Co., Philadelphia, Pa. Mem. A.S.M.E.

caused radical changes in the paper and sugar businesses. We know of a large oil refinery that uses practically no steam while others have a very large steam use. One cannot help but wonder whether some of those using large quantities of steam would not be tempted to change their process if they were not burdened with investments in steam-generating facilities. The loss of the load or a radical change in the steam or electrical requirements of a customer supplied from a special plant may leave idle a large amount of investment, while the normal consumers which are connected to the main distribution system render only a relatively small amount of distribution investment idle when their loads are lost.

These considerations make it appear necessary that a contract be at a rate and for a term which will amortize the power- and steam-generating equipment during the life of the contract, A ten-year contract may cause the rate to be too high to be attractive and it is difficult to persuade industrials to sign fifteen-year contracts. When, due to load growth, it is necessary to increase the installation during the life of a contract, the problem of amortizing the increased investment is present, especially if it is necessary to make the installation during the later years of the contract. Retirements and replacements which will probably occur during the contract must also be provided for.

The economical advantage of this type of plant lies in the ability of the utility company to supply reserve for the generating equipment and to take the excess production or to supply the deficit above the steam demand.

Adding back-pressure turbines in the central supply company's main generating stations is, of course, a more attractive proposition, as the buildings and boiler equipment, etc., are useful for the general business of the company and even the back-pressure turbine unit may be utilized by the installation of a low-pressure unit or by exhausting into existing low-pressure equipment. The opportunity of locating customers within economical steam distribution radius of the main generating stations is generally limited. The feedwater problem, if the condensate is not returned, is also serious as the installation of evaporators takes up pressure head which could be used for power generation.

The form of the corporate set-up and type of rate schedule also offer complications. Considerations as to whether the individual plant should be a part of the public service company or a separate company must be made and this decision has a direct bearing on the form of rate schedule. With a single customer served from the plant, methods of charges are relatively easy of solution but, with two or more customers each having a different ratio of steam to electric requirements, it becomes more difficult to distribute both the fixed and production costs equitably.

The Deepwater station arrangement, referred to in the paper, is interesting in some of the results that have been experienced. I believe the parties to this agreement have faith in the fairness of each other. They know that the differences that have arisen are honest divergences of interpretation of intent and have settled them on a basis of equity rather than trying to take an advantage of literal interpretations of the contract. The satisfaction to the utility companies in this contract is not dependent on receiving either firm capacity or surplus energy from the back-pressure turbine, although it was expected when the contract was signed that both firm capacity and surplus energy would be available. The operation at this plant is an example of the way industrial loads and load characteristics vary and demonstrates why utility engineers are hesitant in considering the power from back-pressure turbines as firm capacity or believing that steam and electrical peaks coincide. At the time the arrangements were entered into, the industrial's engineers thought that the steam and electrical requirements varied together, that the steam used was such that excess energy would always be available, that there would be excess capacity available in the back-pressure turbine which the utility company could count on as firm capacity, and that the industrial would only have to purchase additional power when the back-pressure turbine was out of service.

Now, let's look at the record! It covers the years 1931, 1932, and the first eight months of 1933.

The maximum monthly kilowatthour use was 65 per cent greater than the minimum monthly kilowatthour use

The maximum monthly steam use was 86 per cent greater than the minimum monthly steam use

The kilowatthour required per 1000 lb of steam required varied from 34.6 to 44.7.

The maximum number of kilowatthours that it was necessary to purchase from the power companies' machines to make up for the lack of power generated by the back-pressure turbine was, in one month, 20 per cent of the entire industrial's requirements. In the month of minimum requirements, it was necessary to purchase but $^{24}/_{100}$ of one per cent.

The maximum amount of surplus power from the back-pressure turbine which the power companies could purchase was 10.65 per cent of the total generated. There were five months when the back-pressure turbine produced no surplus that could be purchased. In one month, it was necessary to purchase 10 per cent of the power required by the industrial from the power companies due to shortage in the steam requirements and, during the same month, an amount of power equivalent to 5 per cent of the industrial's consumption was sold back to the power companies. All of the above data were for months in which the back-pressure turbine was in operation throughout the month.

I believe these figures clearly show the unsynchronized use of steam and electrical energy in a large industrial establishment.

James F. Muir[13] wrote: In his review of the many papers, which have been published on the interchange of steam and electric power, Mr. Harkins stresses, in a somewhat unique manner, the necessity of cooperation between industries and power utilities.

The basis for interchange must, of course, be mutual profit, and a spirit of cooperation must necessarily be a function of this objective. If the parties to any prospective interchange plan do not cooperate, there is then no common ground for negotiations or agreement.

In a problem so involved in technical and economic considerations it is but natural that differences of opinion, misunderstandings, and possible disagreements should arise. But when we consider that these same conditions are an every-day occurrence among all kinds of business and among industrials in the same business, it should be a matter of satisfaction that some progress has been made, as evidenced by the author's list of interchange arrangements already in service.

For the purpose of analysis and discussion, it becomes necessary to establish the extent to which the interchange plan can be adopted and to determine the respective responsibilities of the utilities and the industrials in the promotion of this plan.

As a matter of general interest and to give a picture of the entire industrial situation, the author might have included data showing the industrial plants which purchase power from central power systems. While most of these utility customers

[13] Power Engineer, The West Penn Electric Company, Pittsburgh, Pa. Mem. A.S.M.E.

are not in a position to interchange, this information would give an indication and a measure of the extent to which industrials depend on the central-station system for power service.

It is common knowledge that a very large percentage of central-station power is generated for industrial purposes. In fact, in the system I am associated with, more than 80 per cent of the total output is delivered to industrial plants.

In this connection Mr. Harkins discloses that in the $8^1/_2$ million kilowatts of industrial capacity, the average size of generators is 450 kw. Furthermore, the paper states, in effect, that the interconnection of a great many small units presents a hazard and reduces the quality of service to all customers. It is reasonable to expect that this conclusion has been arrived at after a careful analysis of conditions. It must be agreed, therefore, that the average plant is too small to warrant interchange considerations. In any case, our investigations indicate that these average plants have little or no surplus power available and the installation of additional equipment for this purpose cannot be justified.

In considering, then, the plants which are qualified to be included in a study of interchange arrangements, and which are not a part of the central power system, it becomes a vital part of this study to sort out or separate the favorable and unfavorable possibilities.

Plants with large power loads and relatively small process- and heating-steam requirements may be considered as the steam-condensing group. This group, which includes glass, coal and coke, iron and steel, metal products, etc., represents a very large percentage of the plants above the average size. With the greater portion of their power needs generated by condensing units, the advantage of the interchange is of small consequence. Although power from these plants could be delivered by relatively short transmission systems to local customers, this advantage would be offset, to some extent, by the fact that the industry must be served first. The outside customer is of more or less secondary importance. In this group, however, there are a few plants where waste heat and fuel are available. In such cases the installation of interchange capacity might be warranted, but the number of plants in this category represents an insignificant part of the industrial field.

There now remains the group of plants with large steam demands and relatively small power requirements. These types of plants constitute a field for the development of possible interchange arrangements. As a result of investigations in the system in which I am employed, the number of plants having large steam demands and relatively small power requirements represents only one-half of one per cent of all industrial plants in the territory. This territory covers an area of 20,000 square miles and is typical of a highly industrialized region.

In summarizing the situation as outlined above, it is quite evident that the field of interchange is very small indeed, probably consisting of a few of the industrial plants with large steam and small power requirements.

Having arrived at this conclusion by investigation and a consideration of the many factors involved and encountered in industries of almost every description, it would seem appropriate that some further comments be added with respect to the attitude of the industrials in connection with the supply of power.

In the past (and it is likely to apply in the future) industrial concerns have been more interested in investments which would show a high return in manufacturing equipment. While the savings in the power-plant department by high pressures and mercury cycles may show some advantages, these savings would be insignificant compared with the profits on industrial-plant manufacturing equipment investments of the same magnitude. This statement of investment policy is not merely an assumption, it comes directly from both small and large industrial interests. These concerns are not interested in complicating their normal manufacturing activities by power developments beyond their local requirements. They purchase electricity from the central power system because it is profitable to do so and because these purchase agreements can be discontinued should the arrangement prove to be unsatisfactory.

Industrial concerns are specialists in the manufacture of commercial products. In fact they must specialize and concentrate on the improvement of their methods of production and the quality of their goods. These activities result in an almost continual change from year to year, and in some cases, month to month, in processes, in the demand for goods, in equipment of new types and kinds, in the character of business, and in the use and amount of their power and steam demands. In fact, changes are so rapid that the average life of industrial plants is astonishingly short. It is less than a decade.

In operations surrounded by such uncertainties it is only logical that the attitude of industrials should be one that points definitely toward a release from the responsibilities of the technical problems and the highly specialized operations of the power business.

It is a known fact that with but few exceptions industrial power plants are not equipped with steam and electric generators which can compete in performance and production costs with those in service in central power systems. In order to meet this competitive situation and make the interchange plan effective and profitable, new high-pressure steam and electric generating equipment would have to be provided. From our record of 10,000 personal contacts each year with industrials it can be stated with confidence that the vast majority are not interested in the installation of new high-pressure equipment for interchange.

Mr. Harkins points out that the larger part of future electrical generating capacity should very probably be installed in or near industrial plants rather than in condensing-steam and hydro central stations.

The economic advantage of stations conveniently located in industrial centers for the supply of steam as well as power is thoroughly appreciated by the power companies. In fact, in the summer of 1929 our company completed studies and was prepared to undertake an installation of this kind. These plans were upset by the depression and its duration has altered temporarily the power-supply situation. However, as soon as normal business conditions are established, we are fully committed to a policy of active promotion of such schemes as are warranted by sound economic conclusions. Indeed, the major part of my activities are centered around investigations into these possibilities.

Although the development of such projects is governed by the demand for process steam, the turbine equipment in these stations cannot be confined solely to the back-pressure unit as sponsored by the author. Seasonal variations and wide fluctuations in industrial demands would, in most of these installations, result in very inefficient loading of turbines of the back-pressure type.

From the author's comments it is not clear whether he favors the development of these projects by the utilities or by the industrials. It would seem a reasonable assumption that this type of power enterprise is an activity which should, and probably will, be undertaken by the utility. The power companies are in a position to provide high-efficiency condensing base-load plants of capacities considerably in excess of local steam and power loads. Extraction steam would be used for process, and surplus power would be delivered to the system. On account of the larger capacity and the high economic advantage

of base-load operation, the unit cost of production would be reduced to a minimum. A plant of this type would not be affected by changes in manufacturing processes and it would have the same reliability as any modern super-power station.

Let us hope that the few plants of this type already in service will furnish the incentive for more active cooperation between central power companies and industrials in an expansion of this most recent and interesting plan for the development of power facilities.

Regarding the attitude of the utilities with respect to the purchase or interchage of power from industrials, I can, of course, give only an expression of the policy of the company by whom I am employed. It can be stated definitely that we are interested in obtaining adequate and reliable power at any place, provided the cost is in line with incremental value of similar blocks of power from existing plants already in operation in the system.

This discussion has attempted to point out as a result of experience and contact with a great variety of industries, that possible interchange arrangements are more or less insignificant when considered in terms of the industrial field as a whole. However, regardless of the number of possibilities, it is important that the power utilities exercise all possible interest and cooperate to the fullest extent. This, I am sure, is the honest intent of all progressive central power systems.

Geo. A. Orrok[14] wrote: In preparing a discussion of this paper I found that I would greatly exceed the ten minutes allowed me so I prepared an article which appeared in *Power Plant Engineering*, December, 1933, where I have given facts and figures concerning the most interesting interconnection at present in existence, that of the Union Générale Belge d'Electricité.

In the years preceding 1925, Mr. Fernand Courtoy, of Brussels, worked up a plan for the coordination and interconnection of the power supplies of Belgium. This proposal was soon followed by the appointment of a commission whose report was embodied in the law of March 10, 1925, establishing the Union Générale Belge d'Electricité. This corporation grouped together all the large producers and users of power from all sources in the eastern half of Belgium. The size of the plants connected was limited by the requirement that they should take at least from 500 kw to 1500 kw of demand. These plants were connected by high-tension lines into one system managed by the load dispatcher at Liége, and by 1929 an aggregate of about 500,000 kw had joined the system. The higher-cost plants had been shut down or relegated to peak-load operation. The net savings for 1928 operation were more than 4,000,000 francs and the profits to members were of the order of 2 centimes per kwhr for the 1928 operation. In 1929 the profits on a much larger business were about $1^1/_4$ centimes per kwhr. The 1930 business approached 1,000,000,000 kwhr, with profits of about the same figure.

Since the preparation of the article referred to, I have received a letter from Mr. F. Bochkoltz, director of the Union Générale Belge d'Electricité, who tells me that the 150,000-volt transmission line connecting the provinces of Hainaut and Liége has been completed and the paralleling of the entire system is now in operation. The generating capacity is substantially the same as in 1932, while the returns paid to the affiliates have amounted in each year, 1931, 1932, and 1933, to one centime per kilowatthour. He corrects one statement which I made in *Power Plant Engineering* by saying that up to date no government representative has been appointed to the board of directors, although the possibility is provided for in the law of 1927.

J. A. Powell[15] wrote: I am thoroughly in accord with the broad idea of interchange of steam and electric power between industrials and public utilities, having studied this subject for several years.

Such projects, however, should only be executed after a very thorough study has been made, taking into account not only the cost of the steam and electric generation, but also the long-time economy and availability of such generation from industrial plants, the changing energy demand on the utility system, the method of joint plant operation, and the local conditions peculiar to that particular project. For such studies a thoroughly competent engineering organization should be called in, who, with the cooperation of the industrial and the utility, can ascertain all facts and work out a most economical solution for approval.

I have been associated with a number of such investigations during the last four years. In general, the industrial and the utility have fully cooperated in all studies. These studies revealed the necessity of a thorough examination of the conditions for each individual project. Not only should the present steam and power consumption of the industrial be checked, but possible improvements in operation should be investigated, as these may materially affect the steam demand and thereby the result of the study.

In several studies, it was found that an interchange of power between the industrial and the utility was not as favorable as a superficial study seemed to indicate; in other cases, such interchange of power was found definitely economical and feasible. In general, it may be said that an industrial plant must be of a certain magnitude and must be doing a stable business to make it attractive for the utility to connect this plant to its system for power generation.

In one study made, the steam demand of the industrial was approximately 500,000 lb per hr, with a yearly steam requirement of 3.5 billion pounds. The thoroughness of this study, which was completed about two years ago, may be judged from the fact that complete estimates were made for eight arrangements, including installation and operating costs for a plant using steam at 1400 lb, 600 lb, and a mercury boiler. The smallest mercury unit which the manufacturer was willing to install was for 20,000 kw, thereby limiting the benefit of the mercury cycle to the largest industrial plants.

The result of this study was gratifying in that it showed that a plant built for the supply of steam to the industrial and electrical energy to the utility was economical, feasible, and beneficial to both parties. Due to the slump in business conditions which reduced the steam requirements of the industrial and also the energy requirements of the utility, the postponement of the actual installation was necessary. In this case, as in several others, plans are complete and the actual purchase of equipment and installation of units can be made without delay when business conditions warrants such action.

A number of engineers and executives in this country are fully aware of the possibilities of such interchange of steam and electric power and that the studies made will prevent them from the pitfalls of overenthusiasm in a new field, and lead to quick action based on a careful analysis of the facts when conditions permit.

Many joint power projects have unquestionably been delayed, due to cheap fuel and dump hydro power experienced during

[14] Consulting Engineer, Orrok, Myers, and Shoudy, New York, N. Y. Mem. A.S.M.E.

[15] Vice-President, W. S. Barstow & Co., Reading Pa. Mem. A.S.M.E.

the last few years, and difficulty in obtaining new capital for such projects.

Guy B. Randall[16] said: There are so many interesting statements in this paper by Mr. Harkins that it will naturally develop a lot of interesting discussion. But his seven conclusions, well summarized at the end of the paper, must appeal to the vast majority of engineers who have followed this development as being quite sound.

In the body of his paper, as well as in conclusion No. 2, Mr. Harkins, in my opinion, has perhaps unintentionally left an erroneous impression when he makes his brief references to hydroplants. As I have suggested in at least two previous articles dealing with this subject, there can hardly be any serious competition between steam power and water power if our national power development is carried out in a rational way. One has only to visualize the inevitable national, and even international, "power pool" to realize fully the fundamental truth of this statement. A water-power plant not only can be very simply and quickly placed in service and likewise stopped but by drawing on water storage can develop enormous peak-load capacities. Water-power plants can also be arranged in many cases to pump water for storage, thus consuming certain steam-power and water-power surpluses. It is, among other considerations, for reasons such as this that water-power rights will, in the future, prove highly valuable in a unique way. So steam-power development, either on a condensing or a by-product basis, does not operate to make water power useless but rather tends to modify and to enhance the importance of its ultimate economic application. I say this, and yet in the same breath admit I am a "steam" man. But when I talk about a water-power plant I do it "with my fingers crossed." Because, after all, a hydroplant is nothing but an elementary steam plant in disguise. In it the boiler feed pump is simply reversed and magnified to the dimensions of the main prime mover, a hydraulic turbine, while the sun and the ocean act as the heat source and the boiler, respectively. So if anything can be regarded as certain it is that we should not be faced with a problem of steam power versus hydro power but rather with the problem of the proper coordination of our three great steam-power sources, namely, (1) condensing steam, (2) by-product steam, and (3) "hydro steam."

Mr. Harkins follows his water-power statement with a second point which is tied into conclusions Nos. 3, 4, 5, 6, and 7. I do not question these conclusions. But I do think that the paragraph beginning at the bottom of page 12 may reasonably be examined from a slightly different angle. I refer to the general subject of the rights and responsibilities of a utility power company in dealing with an industrial plant as to surplus power and power interchange. The key to the solution of this problem jointly confronting the industries and the utilities is probably to be found in a careful review of the essential character of the utility power companies and their proper relations to the communities they serve. This involves consideration of their obligations no less than their privileges. They are privileged to exercise the right of eminent domain, to occupy streets, roads, and other public places in a monopolistic manner for the conveyance of their product, and to charge such prices as will net them a reasonable or fair return on their investment. Their chief collateral responsibilities are to exercise reasonable prudence in management, to avoid interfering unduly with the use of public places or highways, and to see that service is adequate to meet the ever-changing needs and standards of the communities they serve in this quasi-public relationship. They are in no sense granted any monopoly on the making of electricity. Any one may do that. Nor on the selling of it. Any one may do that. Their monopoly lies in the rather exclusive use of public property for conveying and distributing electricity. That is, they are permitted to install private "powerways" on and under public highways. Now if I have a block of electricity to sell and ten squares down the street another party has a block to buy I, as an ordinary citizen or company, cannot make the sale unless I make delivery over a private transmission line running on private property. That is, I must follow this method, which is usually prohibitively expensive, unless I can prevail upon the power company to do the conveying. In this event, I sell the electricity to the power company, which in turn allows it to flow over their wires to the buyer's premises where they then re-sell it to the buyer. Suppose that as a surplus-power producer I finally induce the utility to make me a price for my surplus. This price, of course, would be discouragingly small as compared to what the customer pays. As an alternative I might then suggest to the utility that they simply place three independent wires on their existing structures and connect me with my customer. At one stroke I have cleared away a wilderness of entanglements and complications. The basis on which the deal may be negotiated now assumes relatively simple proportions. I can make money, the power company can make money, the customer can make money, and the community is better off. This is the common-carrier idea reduced to its simplest terms where electricity is the commodity. The full solution, of course, involves another step which I have, for almost exactly ten years, labeled and described as a "power pool." This great power pool is coming inevitably. Many members here in this meeting can easily recall when it was quite common for railroads to refuse freight originating on other lines. But such a custom could not long prevail because it was so obviously contrary to the public interest. The same reasoning applies to the power problem. Pooling is natural. The only question really open to discussion is how best it may be done. We can recognize it and arrange for an orderly development. Or we can refuse to recognize it but nevertheless will get it through a course of zig-zag progress which will serve mainly to increase both the expense and the time for a given development. So perhaps lexicographers, as well as engineers, should add to waterway, highway, railway, and airway, an equally portentous development logically called "powerway," because, like its four consorts, it will be essentially a common carrier.

In the foregoing I have emphasized in a little different way some of the features of the problem which Mr. Harkins has ably dealt with. These are features which are important, not only for engineers in general but for much of the public to understand. Such understanding will, perhaps, keep us from losing a sense of proportion—a thing which has occurred too often in the past. Mr. Harkins, perhaps, recognized this fact but in one paper cannot include everything. As another industry interchanging power with a utility system, I might add The Champion Coated Paper Company to the list he discusses. This company, in its Hamilton plant alone, generates well over one hundred million kilowatthours per year, sells about ten per cent, and buys about one per cent. The interchange is on "when, as, and if" basis chiefly because of the utility's insistence. The utility's selling price is three times the industrial's. Probably neither party is satisfied with the arrangement though relations are certainly friendly. The satisfactory solution of this case and all other cases must, in the final analysis, depend upon some sort of public agreement as to the principles involved. This in turn calls for a very considerable amount of free and open discussion. The ends of logic, justice, and econ-

[16] Superintendent of Power, Champion Coated Paper Company, Hamilton, Ohio. Mem. A.S.M.E.

omy are not well served by silence, secrecy, or equivocation. The existence of a north pole and a south pole implies an equator. Let us all hope we find it without resort to a complicated legal instrument. Yet some kind of a code will doubtless be necessary for a good many reasons. But it must be remembered the present by-product or surplus-power situation is not exactly something new under the sun. It is rather the old, old story of a natural and gradual technological advance which may ultimately exert enormous pressure—like water freezing in a granite rock—simply because it is constrained.

One peculiar result of this constraint lies in connection with the maximum-demand and emergency-service policy followed by most of the utilities. The set-up is such that if I want to install one thousand kilowatts of capacity to generate some power, the utilities indirectly force me to install another thousand kilowatts of capacity for emergency reserve. I say this because in every case I have known much about it has been cheaper to install used or second-hand equipment in a first-class manner to supply emergency service than to buy it from the utility. I have been a little surprised at some cases where engineers have recommended purchasing emergency service when the used-equipment solution would pay 20 to 100 per cent yearly dividends. In this connection used equipment—or old equipment—is not to be taken lightly. A keen engineer can often accomplish wonders with it for service with a 5- or 10-per cent use factor. And, believe it or not, some of the old equipment is better for standby service than some of the new. But most utilities seem to feel that in any event this reserve equipment is an industrial plant's own ghost. I am not so sure. I often wonder if, in the natural course of future events, the utilities may not some night awaken in a cold sweat to find it haunting them.

Whatever the material facts may be there is little ground for belief that industrial plants, as surplus-power producers, will receive unprejudiced consideration of their claims by the utilities except as they arrange to press them diligently. If any one is inclined to doubt this statement, let him investigate the known facts of electric-appliance retailing and the laws that have been passed—or are pending—in many states to govern it. Much information is available in this connection from the various state retail associations. But this very situation offers a unique opportunity to the utilities to demonstrate that they do realize and do assume the responsibilities as well as the privileges conferred through their public-granted monopoly for conveying and distributing electricity. If they do make use of this opportunity they will not only have an added reason for further development but will rise above that level of thought and action that now seems to justify applying to some of them that old but logical and classical injunction, "There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy."

In closing, I feel compelled to mention once more[17] the moot point as to the necessity for evaporators. All who have read this paper must have noticed that in Table 1 there is a curious recession in the kilowatts of power available when the increasing steam pressure reaches 650 lb. This simply means that Mr. Smith thinks evaporators are not required at 450 lb but are required at 650 lb. There is an abundance of actual operating evidence that they are not needed up to approximately 750 lb, inclusive. The recognized authorities on feedwater and boiler-water-control also seem to agree that they are not needed for 1300-lb operation. Operation of the plant with which I am connected has been notably successful and free from trouble of any kind without evaporators and with a make-up of 35 per cent of hard water for 650-lb operation. I think the secret—if indeed there is any secret as some seem to think—is that water-treatment plants must be controlled by the hour rather than by the week. With evaporators or without evaporators first-class control is economically necessary because it pays handsome dividends to those who exercise it.

[17] See Trans. A.S.M.E., 1931, paper FSP-53-26a, p. 346.

C. Richard Soderberg[18] wrote: It is a curious fact that, although the fundamentals of the problem of interchanging steam and electric power have been well known for a long time, it is only during recent years that it has received due attention. Of the available possibilities of materially improving the efficiency of power generation, the generation of by-product power offers by far the greatest possibilities, wherever there is a demand for steam for heating purposes. It will eventually transform a large percentage of our industry from power consumers into efficient power-generating stations. The author has ably brought out the inherent facts of this problem.

It is in this field that the development toward higher initial steam conditions is bound to come into its own. The principal objection to high pressure, namely, the wetness in the exhaust of condensing turbines, is removed when the expansion is interrupted at the range of pressure generally used in industrial heating application. In this connection, I should like to call attention to the next to the last item in Table 1 where steam is expanded from 2400 lb per sq in., 1000 F, to 200 lb per sq in. with a by-product power generation of 24,050 kw for an exhaust steam flow of 400,000 lb per hr. This is presumably obtained on the assumption of no extraction for feed heating. Regenerative feed heating is of particular importance in this connection, however. When this device is brought into the picture, it will be found that the by-product power available comes close to the value obtained by the mercury process. Considering, for example, the more practical case of 2400 lb per sq in., 900 F, exhausting to 200 lb per sq in., and extracting for feedheating in three stages, including at the exhaust pressure, it is possible to generate about 35,000 kw for a steam flow to the process line of 400,000 lb per hr.

W. B. Skinkle.[19] There is so much to be said on the possibilities resulting from the interchange of power facilities as between two industrial companies or between the industrial and the utility that it is difficult to determine what should be left out in order to bring the discussion within the limit of the time allowed.

This paper by Mr. Harkins very effectively handles a problem to which the writer has given a great deal of study during the past fifteen years. He should be complimented on the brief yet able way in which he has treated this subject which is capable of an almost infinite number of variations.

The author makes one statement in his paper as follows: "if industrial management were educated in the economics of power generation, etc.," to which I should like to make a considerable enlargement. The writer believes this statement should read: "If utility and industrial management, operators, and engineers were educated in the general subject of industrial economics, etc."

The inability of each group to visualize and recognize problems faced by the other group is one of the major stumbling blocks in the conclusion of sound interchange agreements.

Fundamental Economics. The two large oversights occurring in both groups are a failure to recognize and properly evaluate

[18] Manager, Turbine Apparatus Division, Westinghouse Elec. & Mfg. Co., South Philadelphia Works, Philadelphia, Pa. Mem. A.S.M.E.

[19] Secretary and Engineer, Pittsburgh District Power Committee, United States Steel Corp., Pittsburgh, Pa.

the "time factor" in production, and second, a failure to realize that this mythical thing called "cost" is subject to considerable analysis and variation. There very decidedly *is* such a thing as a "constant" cost which is independent of the production and there is also such a thing as an "increment" or "out-of-pocket" cost which is dependent on the production and which varies widely in accordance with a constantly changing set of operating conditions.

It has been gratifying to note how this present industrial depression is educating all classes of both utility and industrial men into some of these basic facts in industrial economics.

Attention is called to one point illustrated by Fig. 2 of Mr. Harkins' paper (see page 13) which it is believed is generally overlooked.

Without considerable study and analysis of the subject, most

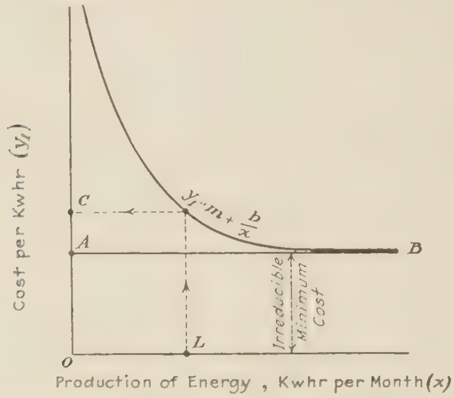


Fig. 3 Typical Unit-Cost Production Curve

people assume that the great value of interchange results from the recovery of industrial by-product heat and the conversion of this heat into power. Without the all-important "time factor," energy recovered from industrial by-product heat, while not absolutely valueless, has in fact only a very small value as it must compete with the "increment" or "out-of-pocket" fuel cost of large utility equipment capable of putting a kwhr on the station bus bar at an expenditure of between three-fourths of a pound and one pound of coal.

It is quite remarkable to note from a close study of Fig. 2 what a small and almost insignificant quantity of "firm" power will be exchanged between the two systems.

The area under the line "*CD*" represents the quantity of energy developed by the utility whereas only the small vertically sectioned areas between the vertical lines 2 to 3 and 6 to 7 represent the help from industrial sources that is actually required by the utility company. The situation with the industrial is similar, where the diagonal dotted cross-sectioned areas between the vertical lines 4 and 5, and 9 and 10 represent the utility help in the form of "firm" power actually required by the industrial.

It appears, therefore, that the chief advantage of interchange arises from the exchange of emergency power and the ability of the two systems to delay large investments in power equipment which, under independent development would have to be completely installed before any part of its output would be required and would then have to stand idle accumulating a high cost in fixed charges until the load grows to a point where its operation becomes necessary.

The addition of generating equipment on a major utility system can easily cost as much as $6,000,000 which if delayed for one year means the avoidance of approximately $780,000 expense in fixed charges. A large industrial plant may easily invest $2,000,000 in addition to power facilities on which the fixed charges would amount to $260,000 a year. With utility support, the industrial plant could probably delay investments much longer than would be possible in the case of a utility plant.

During the past ten years I have had occasion to develop the economies involved in several interchange problems. It is my opinion that a sufficient number of interesting points were developed to make a review of some of these problems particularly opportune at the present time.

Fundamental Economics

In order to clarify the points presented it will be necessary to make a short review of some of the fundamentals of industrial economics which have already been presented in other papers but which it is believed will stand repetition.

Fig. 3 is a typical curve of unit costs plotted against production and illustrates how the unit cost decreases with increased production until it approaches an irreducible minimum.

It can be shown that such a typical curve answers the general definition of a hyperbola of the form of

$$y_1 = m + b/x$$

If the total operating cost for any given rate of production is wanted, the units produced *OL* would be multiplied by the

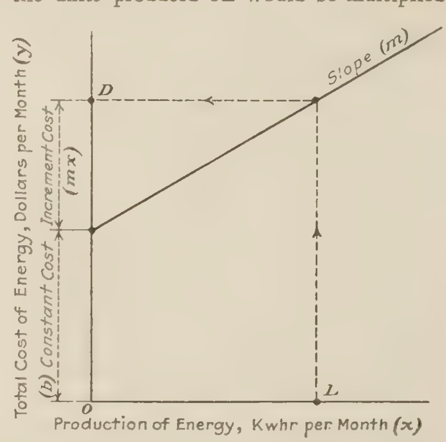


Fig. 4 Typical Total Cost-Production Curve

unit cost *OC*. It can be shown also that the curve of Fig. 3 can be expanded into a total cost curve like Fig. 4, which is a typical curve of total cost plotted against production.

In this figure the total cost is shown to be made up of two parts: A constant cost b, which is independent of the production plus an increment cost mx, which varies directly as the production.

The truth and practical application of this conception of costs have been proved many times in the writer's investigation of industrial economies. An interesting side light to the foregoing is shown in Fig. 5.

Variations in efficiency of the units in question change only the slope of the increment-cost line so that economies resulting from increased efficiency are dependent on a large production for satisfactory results, whereas changes in the constant cost of operating a given unit hold throughout the entire range of production. This principle has been of great value during the present periods of low production in pointing out those elements of cost on which attention and effort should be concentrated.

As an actual illustration of how closely industrial costs follow this principle, Fig. 6 is offered for inspection.

In Fig. 6(*a*) actual "book costs" for every month of three consecutive years are plotted for a boiler house of about 3500 hp of rated capacity. The variations from the cost lines shown on the graph are accounted for by changes in the cost of coal and also by the fact that repairs and "distributive costs" shown on the lower line are charged "in total" against the production of the month in which the expense is incurred. This means that although many items of repair and similar costs gradually accumulate over long periods of time, the production during the month in which the money is actually spent gets "soaked" with the entire burden. In Fig. 6(*b*), the repair costs and similar items were "funded." A given constant plus an increment was charged against each month, so that months of large production carried a greater amount of these costs than months of smaller production. The fuel costs were then charged at the weighted average cost of the fuel.

This particular installation usually operated as a "make-up" unit to supply any deficiency in the by-product heat. During periods of low operation by-product heat was not available and the coal boilers were called upon for heavy production whereas at other times with a plentiful supply of by-product heat the coal station floated on the line and only picked up the load for short periods of deficiency in the supply of by-product heat.

The result is an unusually wide variation in load, this being something over 600 per cent. The points on the cost line show how closely actual costs follow this principle when the unavoidable variations in costs of raw material and some of the peculiarities in accounting practises are removed.

Many similar analyses of steam costs have been made with equally uniform results. This particular example was used because of the extremely wide variation in the steam production. Before leaving this analysis your attention is called again to the irregularities in the book costs of steam as shown in Fig. 6(*a*). The same irregularities occur in the turbine room costs when taken by themselves. Usually when the

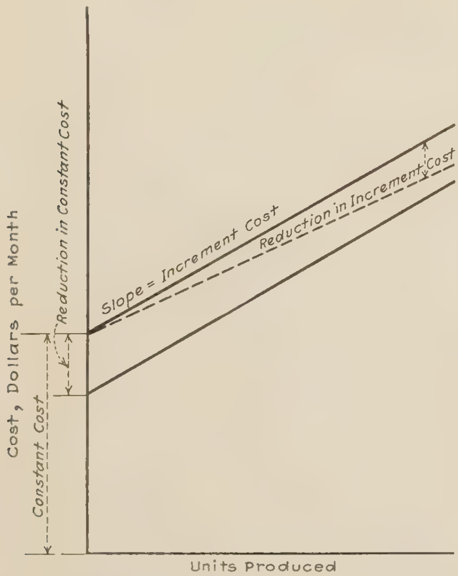


FIG. 5 COMPARISON OF INCREMENT COST AND CONSTANT COST

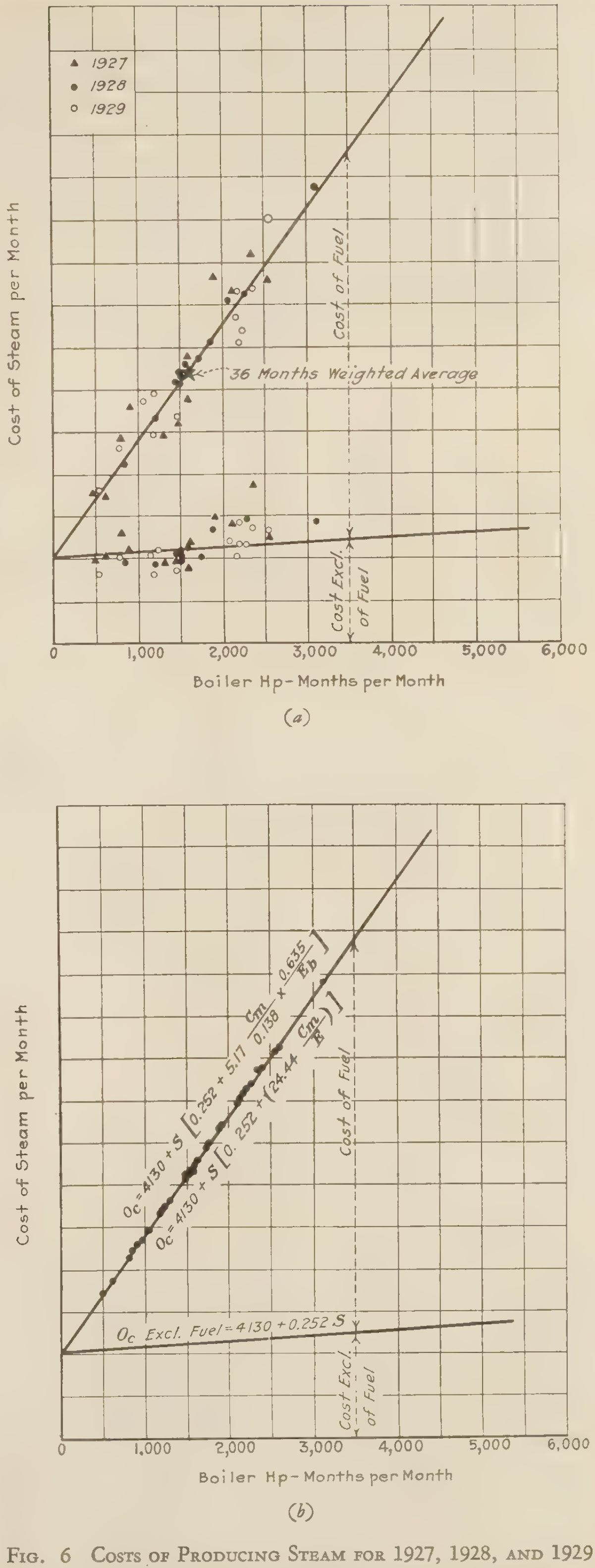


FIG. 6 COSTS OF PRODUCING STEAM FOR 1927, 1928, AND 1929
[(*a*) Book Cost. (*b*) Corrected Cost Based on 63.5 Per Cent Boiler Efficiency and Fuel at 13.8 Cents per Million Btu.]

turbine is shut down for repairs the boilers are "down" and also undergoing repairs with the result that these irregularities are cumulative and electric costs look something like those shown in Fig. 7 where the total cost of 33 consecutive months of operation is plotted against the production of the unit.

Fig. 8 shows the analysis of costs on this unit. The difference in unit cost between the points 2 and 5 is nearly 240 per cent.

Figs. 7 and 8 have been shown to illustrate the difficulties in attempting to formulate economically sound interchange agreements based on the book costs as reflected in the cost sheets of the average industrial plant.

With this background of the fundamental economics, let us see what can be done in an actual case.

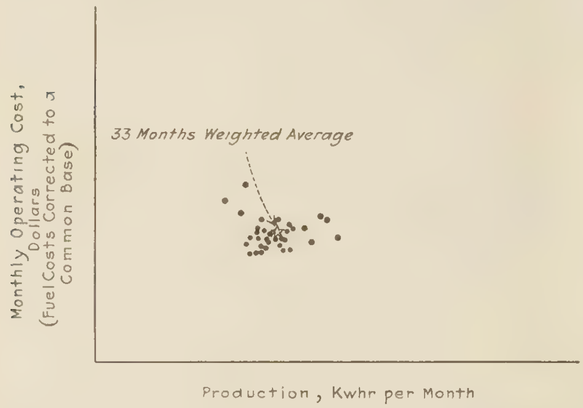


Fig. 7 Turbo-Generator Station Costs Plotted Against Production

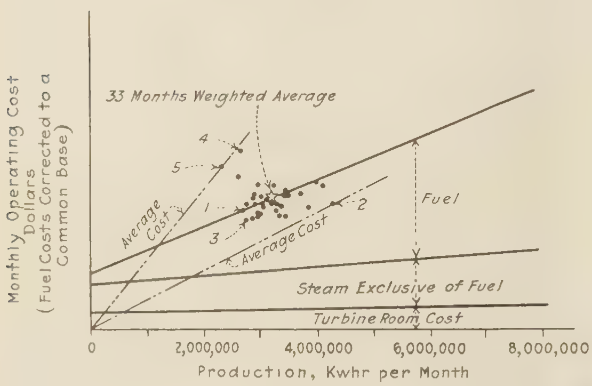


Fig. 8 Variations in Power Plant Cost Sheets

Case 1 Steam Interchange. Two companies called company "C" and company "A" operate adjoining properties. Company "C" has a large modern boiler house and company "A" a 30-year-old boiler house.

The economies possible are the elimination of the "constant cost" of operating boiler house "A" and the supply of the joint steam from boiler house "C." The coal-fired boilers of company "C" are "make up" boilers and are required to float on the line when large quantities of by-product heat are available.

The analysis of the company "C" steam costs from coal are shown in Fig. 9 with (*a*) the book costs and (*b*) the corrected costs.

In similar manner the steam costs of company "A" are shown in Fig. 10. There was, however, a correction that had to be

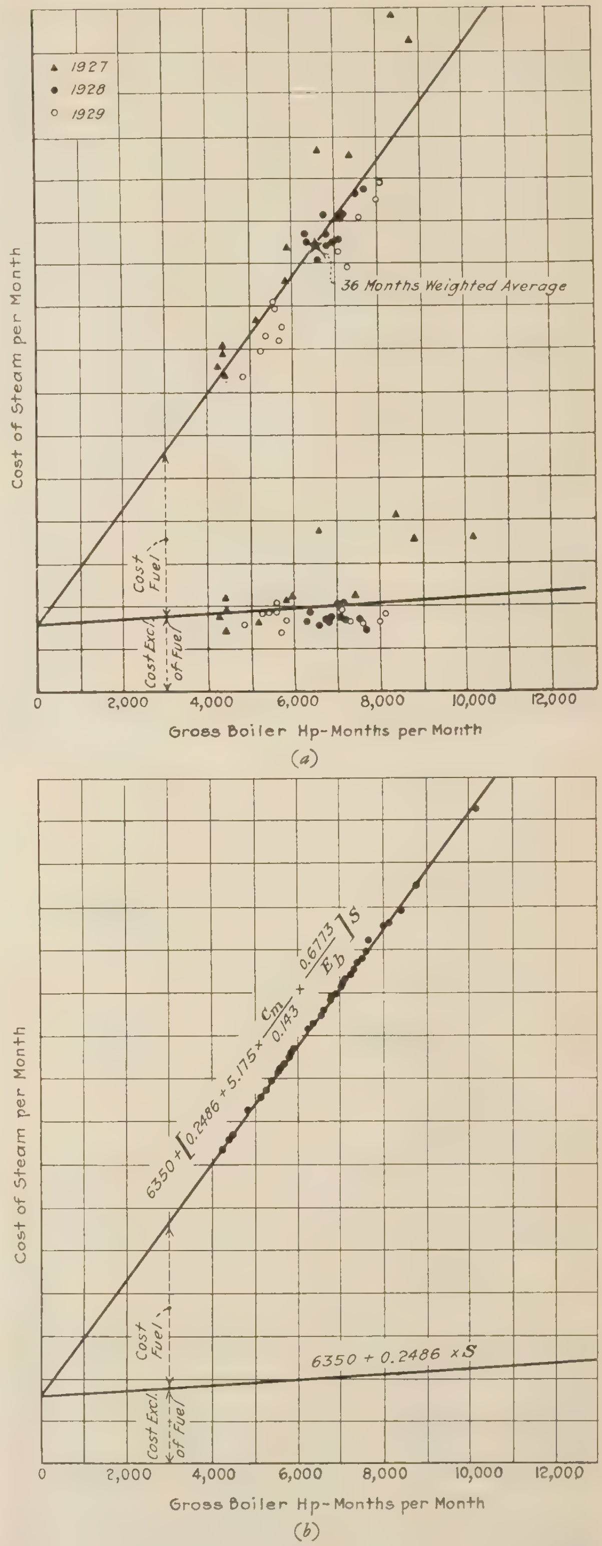
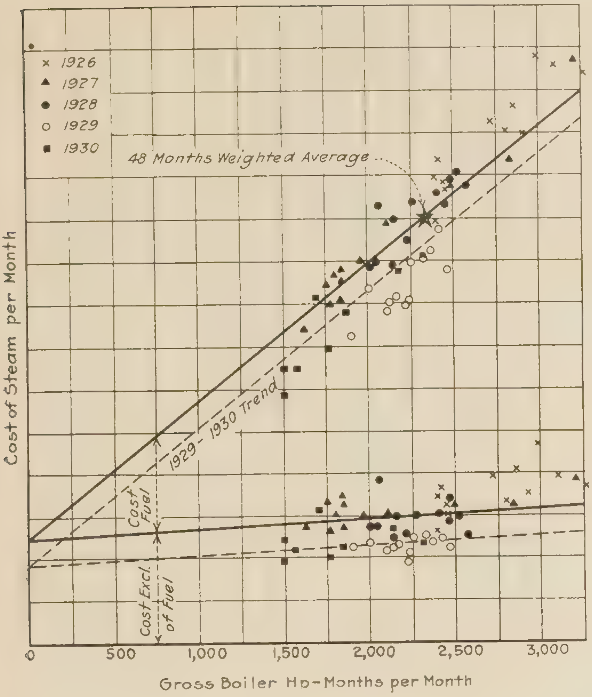
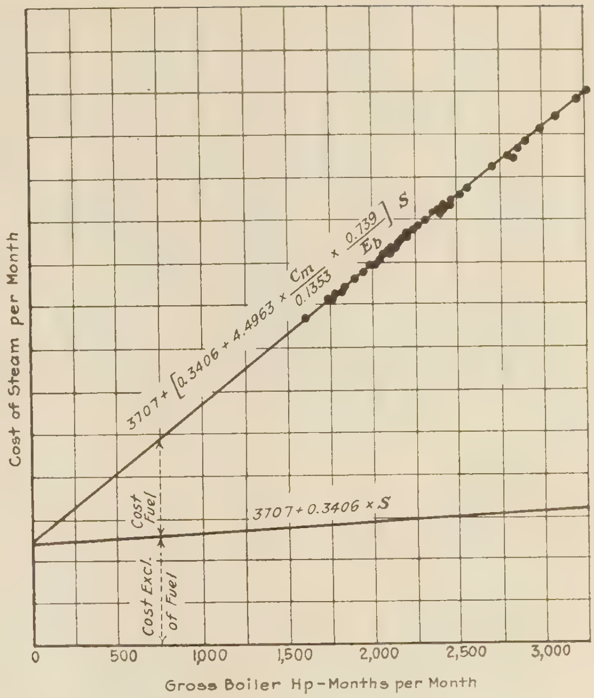


Fig. 9 Cost of Producing Steam for 1927, 1928, and 1929—Company "C"

[(*a*) Book Cost. (*b*) Corrected Cost Based on 67.73 Per Cent Boiler Efficiency and Fuel at 14.3 Cents per Million Btu.]



(a)



(b)

Fig. 10 Costs of Producing Steam for 1926, 1927, 1928, and 1929—Company "A"
[(*a*) Book Cost. (*b*) Corrected Cost Based on 73.9 Per Cent Boiler Efficiency and Fuel at 13.53 Cents per Million Btu.]

made in these costs. If you will notice the costs, exclusive of fuel for 1929 and 1930 are materially lower than similar costs for other years. This shows clearly the results of efforts on the part of the operators of company "A" to reduce their costs. The basis of intercharge between these two companies was therefore made using a constant boiler-house cost of $2800 a month for company "A" instead of $3707 as was indicated by the five-year analysis.

If the total cost of both boiler houses were to be plotted together, the graph would look like Fig. 11(*a*), in which the load and cost graph of company "A" is superimposed on the load and cost graph of company "C."

Changes in either the cost of fuel or in the efficiency of operation of either boiler plant will cause the increment cost lines to change their slope using their points of origin as centers. The interchange agreement is now faced with the problem of dividing a positive but always changing cost reduction equally between the participating parties.

The manner in which this was accomplished is shown in Fig. 11(*b*) which is an enlargement of the upper portion of Fig. 11(*a*). The lines *A* and *B* of Fig. 11(*a*) form the coordinate on which Fig. 11(*b*) is built.

It was assumed that inasmuch as both companies purchased coal from the same mine the fuel cost C_m would be the same for both boiler houses.

It was also assumed that inasmuch as the average efficiency of boiler house "A" over a four-year period had been maintained at 73.9 per cent it was fair to assume that such a figure should continue to be maintained and should, therefore, be used in estimating the probable costs after the boilers were shut down.

The assumption of a constant efficiency enables the cost equation of company "A" to be simplified to the form shown on the upper line of Fig. 11(*b*).

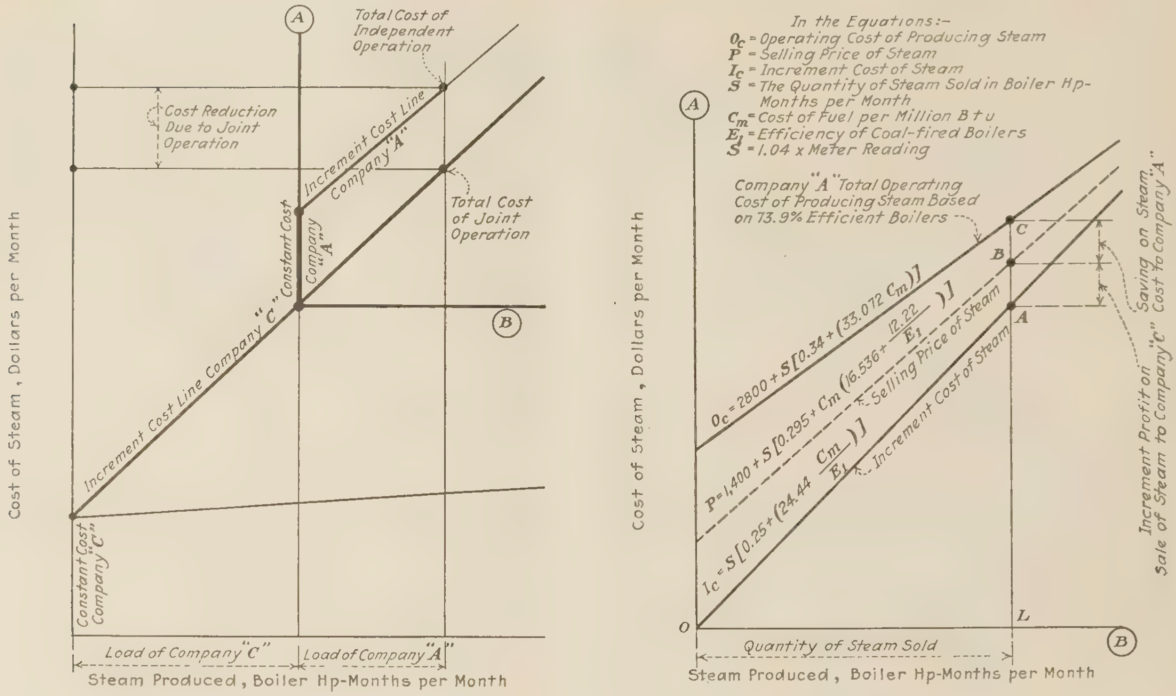
The increment cost of company "C" is shown on the lower line. If these two costs are then added together and divided by two the result will be a selling price that no matter what change in fuel cost or what change in efficiency takes place, the cost reduction resulting from joint operation will be divided equally between the two participating companies. This equation is shown along the central dotted line in Fig. 11(*b*).

Case 2 Interchange of Electric Energy. Interchange of electric energy between utilities and industrials is possible mainly when the industrial has at his disposal large quantities of by-product fuel available in such form that it is not possible or economical to store it or to dispose of it in the form of fuel or in any other manner.

Problems of this kind open up a vast field of special conditions which may radically change from one hour to the next. The difficulties in drawing up agreements which are sufficiently flexible to meet these ever-changing conditions are very great unless the men conducting the negotiations are well versed in the field of cost analysis and industrial economics.

The most essential feature for the successful operation of such agreements is that both parties must benefit financially from *all* parts of its operation.

Industrials generally fail to recognize that there are several kinds of kilowatthours which it may receive from or deliver to a utility, and that each of these different kinds of energy has radically different values to the receiver and radically different costs to the producer. Until this fact is recognized and admitted by the industrial, interchange negotiations will simply become a case of "horse trading" whereby the utility



(a) (b)

Fig. 11 Load-Cost Relationships

[(a) Total Costs of Individual and Joint Operation. (b) Saving and Profit in Joint Operation.]

representatives will "hope" to effect an agreement out of which they can make some money regardless of the benefits accruing to the customer, and the industrial has hopes along exactly similar lines.

Needless to say agreements built on such a foundation will be terminated as soon as the party who is losing money recognizes the fact and can bring the agreement to an end.

Interchanged energy can be of four different kinds, namely:

(1) Firm power sold under regular contracts and available at any time up to the limits of the equipment or contract.

(2) Surplus power available by reason of surplus generating capacity idle and awaiting growth of the system on which it is installed.

(3) Dump power available from surplus by-product heat in the industrial system, which it is not practicable or economical to store or hold in reserve.

(4) Emergency power available from either system to the other on short notice in order to meet sudden, unforeseen difficulties.

Different values should be assigned to each of these, and the number of these values is doubled depending on whether or not the exchange is made during "on-peak" or "off-peak" hours of the utility.

Peak firm power should carry every item of cost that can be charged to it. This includes fixed charges, sales and executive costs, all operating costs, and losses.

The utilities recognize the value of firm power sales secured in "off-peak" hours by placing a low energy charge of 4, 5, or 6 mills on all power sold at load factors above from 25 per cent to 40 per cent. Some utilities go further by removing power factor penalty clauses during off-peak hours or by allowing the customer to create demands much higher than their "on-peak" demands, during off-peak hours without the increased bill that these high demands would normally require.

Surplus power costs should omit many items that enter into the cost of firm power. Investments in equipment are already made and the complete organization is already set up and operating. Additional power under these conditions can be produced for very little over the increment fuel cost.

Dump power from the industrial to the utility is of very low value. The utility must keep equipment operating and prepared to pick up the load carried by the dump power, the instant there is a failure in the industrial supply of by-product fuel. The maximum value that can legitimately be assigned to dump power is, therefore, the lowest "increment" or "out-of-pocket" cost of power to the utility, plus line losses to the point where the two systems are connected. The geographical location of the industrial with relation to the utility generating station is therefore of importance. The price of this kind of power should be based on consideration of these facts and should be protected by suitable coal-cost clauses.

Emergency power values are subject to considerable negotiation as it is almost impossible to place values on this type of service. The costs of these various types of power can be seen readily by referring to Fig. 12.

"On-peak" firm power costs are shown by the vertical height from the base to the line *GH;* "off-peak" firm power by the vertical height between the lines *AB* and *GH;* and surplus power costs by the slope of the line *GH* and should vary from approximately $1^1/_2$ mills per kwhr with very low cost fuel, to $3^1/_2$ mills or even 4 mills in small stations using higher priced fuel.

Dump Power. In the case of dump power made from surplus by-product fuel which must be either converted into electric energy in an already operating station or discharged into the

atmosphere, the cost of this conversion is very small. By referring to Fig. 12 it will be seen that there is no change in the fixed charges and that all the constant costs are already being absorbed. If no other use can be found immediately for the surplus fuel its value to the industrial is zero. The only part of the costs which do increase is a very small part of the repairs, due to the increased load, a little of the water-treating costs for additional steam and a little more water pumping for the condenser. This increase in costs is represented by the slope of the line *EF* and in actual money would be approximately $^4/_{10}$ of one mill per kwhr.

Analysis of an Interchange Agreement. On the cost basis set forth, an interchange agreement was worked out several years ago. This had for its fundamental concept an equal division of any economies that might result from the interchange between the two parties to the agreement.

Surplus and emergency power were worked out according to a schedule shown in Fig. 13.

In this figure the vertical ordinate is "total cost in dollars" and the horizontal ordinate is "kwhr of energy."

The full lines show cost of power on the station bus bars to the industrial and the dotted lines show the cost of energy in various conditions according to the terms of the interchange rates. The entire figure is similar to the final steam diagram shown in Fig. 11(*b*).

The lower line *OA* represents the utility increment cost of surplus power and includes increment station costs, line losses

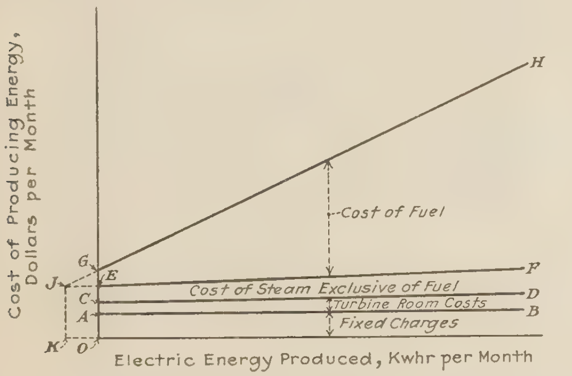


FIG. 12 ELEMENTS OF ELECTRIC POWER COSTS

to the interchange point, and some taxes that would result from the power sales.

The next line *ONB* is the interchange rate based on 60-cycle, 22,000-volt energy above which are two lines showing the unavoidable conversion losses necessary to make the energy available at 25 cycles, 6600 volts.

The vertical line *L* to *R* at approximately $3^1/_2$ million kwhr per month is the estimated point of average operation. It will be noticed that at this point the utility increment costs would be equivalent to the vertical heights *LM*. The utility selling price would be *LN* and the utility profit would be *MN*. The unavoidable losses would be *NP* and the industrial saving would be *PQ*. The last assumes that the industrial has available by-product fuel which it dissipates rather than make the immediate investment necessary to convert this fuel into electric energy.

The general surplus power rate was fixed at 4 mills per kwhr as indicated by the light line originating at *O*, the continuation of which forms the right end of the line *OB*.

In order to handle emergency power sales and "on-peak" surplus power sales the original slope of this line from the origin at *O* is made very steep. The slope and positions of the lines *JN* and *KP* were placed so as to make as nearly as possible an equal division of the resulting economies.

This could not be accomplished through all loads. It is evident from a glance at the figure that the utility cost line *OA* will cross the industrial cost line *EF* and this crossing point is the limit to which cooperation can be carried without involving an economic loss.

The *EF* cost line is used because the industrial already had available sufficient by-product fuel to produce the required energy. The fuel cost for the proposed unit was, therefore, considered to be zero.

The equal division was further complicated by the unavoidable conversion losses between the two systems which, as the figure shows, further reduced the point of profitable cooperation between the two companies.

Where the steep slope originating at *O* intersected the line

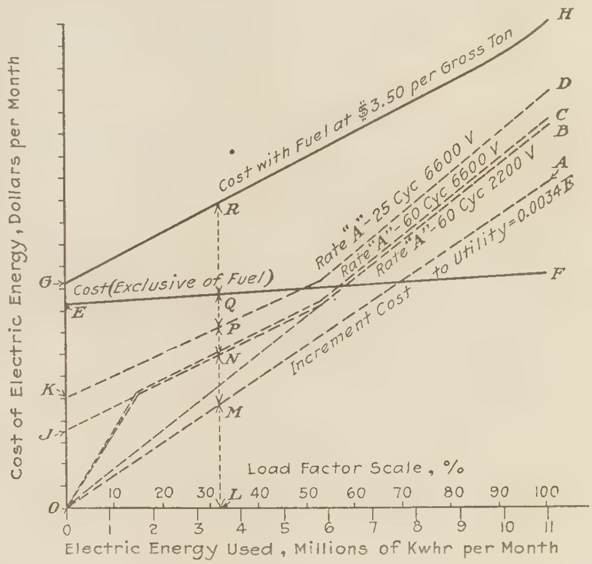


FIG. 13 SURPLUS AND EMERGENCY POWER SCHEDULE

JN the rate slope flattened out until a load was reached that made the average sale price of 4 mills. From this point on the surplus power rate remained at 4 mills.

Surplus power agreements could be made and canceled by either party at any time it proved acceptable to the other party. If, however, any agreement was made for a long period, it was subject to cancelation on eighteen months' notice. This period of time being agreed upon as sufficient to enable the purchasing party to either build his own power plant extension or make other provision to secure the power. The industrial power supply was always protected by reason of the fact that he could at any time make application to the utility for a a supply of power under the regular wholesale tariffs. The utility could not refuse the supply under these last conditions. Dump power from the industrial to the utility required only 24 hours' notice of the amount to be dumped in order to make it acceptable.

Variations of 50 per cent above and below the estimated amounts were allowed.

The purchaser was required to pay for at least 50 per cent of the contracted power for any given day and pay emergency rates for all over 150 per cent of the daily contracts both in demand and energy.

Engineers of both the utility and the industrial plants after careful study of the provisions of the agreement believed that it was sufficiently flexible to permit unrestricted interchange and yet be profitable to both parties to the agreement.

There is one peculiar point in this agreement, however, to which attention should be called.

Usually when two companies agree to do business together the greater the volume of business the greater the profits. A glance at Fig. 13 shows that the agreement is decidedly contrary to this.

It will be noticed that at about $5^1/_2$ million kwhr per month the industrial profit becomes zero and at all loads between $1^1/_2$ million and $5^1/_2$ million kwhr the utility profit decreases.

This seems to indicate that the right to interchange and to secure emergency service is a valuable asset even if no use of the service is made. It also tends to justify the much debated contention of the utility companies on their "ready-to-serve" charge.

The Legal Aspect. There is one other very serious obstacle to interchange to which attention should be called, and that is the legal aspect.

When the interchange agreement just described was completed and in a form satisfactory to both engineers and attorneys it was placed before the Public Service Commission for examination and suggestion.

The Commission's engineers and rate men were very much interested and pleased with the manner in which the project had been handled. The proposed rates were closely examined and the unanimous opinion was expressed that so far as they could see there was nothing in either rate or agreement that was discriminatory or detrimental to the public interest, but right there the matter stopped. When asked what steps should be taken to get the Commission's formal approval before large capital investments were made it was found that there were no steps.

It was explained that the Commission could act only in case of a complaint. If such a complaint were made the Commission would hold a hearing on the case and then, if nothing detrimental to the public interest was found and the complainant failed to show discrimination, the Commission would issue its approval.

In the meantime a large investment, made in good faith by both parties to the agreement, would be seriously jeopardized.

It is believed that serious thought should be given by legislative bodies to this phase of the subject if industrial development along economic lines is to be encouraged.

Neither an industrial nor a utility would care to make investments ranging anywhere from \$50,000 to \$1,000,000 for equipment which they would be liable to find useless on their hands because of unfavorable decisions that could in no manner be foreseen.

In Conclusion. Agreements of the interchange type are of necessity subordinate to the main business objects of the participants and operate in what might be termed the edges or fringes of the field of industrial economics. Efforts to make economies in this field therefore require a broad knowledge of the elements which go to build up costs and an equally broad knowledge of economics. Any changes in operating methods must be carefully examined to avoid interference with the main business of the participants or with effective operations. It is hoped that some of the chief problems that will be encountered in this field and methods for attacking their solution have been pointed out.

Author's Closure

It is very gratifying to review the thoughtful and thorough discussions presented by so many capable engineers. It is unfortunate that the discussions indicate that we are still far from a meeting of minds which will result in a united cooperative effort along the line indicated in my paper. Evidently, individual experience leads to very different conclusions. Professor Christie agrees with my condemnation of the utilities' sales campaign as forcefully as Mr. Dyckerhoff praises their cooperative attitude.

Mr. Dreyfus, Mr. Dyckerhoff, Mr. Hirshfeld, Mr. Irwin, Mr. Muir, and Mr. Powell all emphasize the possible disadvantages of cooperating with *individual* industrial plants. The reasons advanced are beyond dispute; a plant may suspend operations, change its load, its load factor, or its process. Many plants do all these things. Yet utilities find it profitable to sell electrical energy to them. The same diversity factor, statistical effect, and business stability can be obtained by *numerous* cooperative or purchase agreements. The study of the individual case is no study of the whole problem. I urge regional surveys and experimental published purchase rates by utilities as the only proper approach.

Mr. Dyckerhoff, Mr. Muir, and Mr. Orrok point out the commercial and technical difficulties existing by reason of the small capacity and great number of industrial plants. Each of the great majority of consumers has a one-kw demand and a minimum monthly bill of one dollar. With this in mind, it is difficult to believe that the economic and technical problems cannot be solved if we attempt to include in our systems industrial generating stations averaging 450 kw. The careful engineer will be content to say that the technique is not yet developed.

Mr. Hirshfeld presents impressive evidence against the superficial attractiveness of by-product electricity when he gives reasons why central-heating plants do not usually employ back-pressure turbines. I think the picture would be more complete and less conclusive if he had added these three: old franchises do not always permit electrical generation; the unsolved problem of allocating cost between exhaust steam and by-product electricity may bring the utility into an uncomfortable position before rate-supervising commissions; and only very recently has the art of feedwater treatment permitted the construction of extremely efficient high-pressure central-heating plants.

In the first part of his discussion, Mr. Irwin proves that surplus industrial energy is of no value to the utility. In the latter part he complains because he gets none from Deepwater Station. He gets very little because the contract price is so low that the industrial company has every reason to invent new uses for this energy and has no incentive for selling. Mr. Irwin's statistics are correct but do not represent the actual steam and electric loads of the industrial plant. The industrial company operates its own boilers and turbines from time to time to secure the lowest possible power cost. The terms of the Deepwater contract and fluctuations in oil and coal prices occasionally make such operation profitable. It is conceded that steam and electric loads are not synchronized. But I think Mr. Irwin will admit that the stability of the industrial load throughout the depression was better than that of his system load. It leads one to believe that supplying steam and electricity to an industrial plant does not make the utility business more hazardous.

It is gratifying to hear from Messrs. Cather, Irwin, and Powell that new cooperative arrangements of some magnitude may be expected with an improvement in business. Such progress should encourage us all to real cooperative effort in reducing both utility and industrial-power cost. Mr. Hobbs shows us the true cooperative method of attack.

A New Method of Investigating Performance of Bearing Metals

By JOHN R. CONNELLY,[1] BETHLEHEM, PA.

Any method to be used to investigate the performance of bearing metals should reproduce wear under service conditions and in addition it should show variation in wear with unit pressure. Various methods have been proposed in the past, one of which involves an accelerated test using an abrasive between two surfaces rubbing across each other, and another utilizes two tangent cylinders rotating relatively to each other and making contact along their common element. The first method does not reproduce wear under service conditions, while the second results in a constant contact area so that in order to test a metal completely many runs must be made at various unit pressures. The new method described in this paper reproduces wear under service conditions and gives variation in rate of wear with unit pressure.

THE essential elements of the new test are a specimen of bearing metal with one side machined to a plane surface and a steel cylinder rotating in a bath of lubricant (see Fig. 1). A constant force holds the specimen of bearing metal with its plane side tangent to the cylinder.

As the cylinder rotates, a depression is worn in the specimen of bearing metal (see Fig. 2). With a constant force holding the surfaces together, this increase in contact area gives a decrease in unit pressure and the test continues until there is no measurable increase in the depth of the depression.

The characteristics of the new test are:

(*a*) The conditions existing in an actual bearing are reproduced as to lubrication, metals used, physical proportions, and wear. Wear in the presence of a lubricant results from high unit pressures

(*b*) The validity of the test data is independent of any assumption that data on abrasion are directly convertible to data on wear

(*c*) The feature of varying area of contact gives rate of wear for a wide range of unit pressures. An investigator using a test involving a constant area of specimen must necessarily make a great number of runs, each at a different unit pressure

(*d*) The data obtained are directly usable for design purposes.

[1] Instructor, Dept. of Mechanical Engineering, Lehigh University. Jun. A.S.M.E. Mr. Connelly was graduated in 1927 with the degree of B.S. in mechanical engineering from the University of Illinois and received the degree of M.S. from the same institution in 1929. During 1927 and 1928 he was with the Illinois Power & Light Corporation in the capacity of junior mechanical engineer and in 1929 as special research assistant for the Engineering Experiment Station at the University of Illinois. In the fall of 1929 Mr. Connelly joined the staff of Lehigh University and received the degree of M.A. in 1934.

Contributed by the Iron and Steel Division and presented at the Annual Meeting, New York, N. Y., December 4 to 8, 1933, of The American Society of Mechanical Engineers.

Analysis of a Machine Bearing

No matter how careful and painstaking the manufacture and assembly of a sliding-contact bearing may be, it is practically impossible to have the mating surfaces absolutely aligned so that the load shall be evenly distributed over the surface intended to carry it. As a result, the actual surface in contact is reduced so that high unit pressures exist at points on the surface.

The first stage in the life of a sliding-contact bearing is a period during which the surface in contact wears away until a "fit" is obtained. That is, as the bearing metal wears, the area of surface in contact gradually increases. This permits the load to spread itself over a greater area with a reduction in unit pressure. Wear continues until the maximum unit pressure existing in the bearing is insufficient to rupture the oil film. Such a condition completes the first stage. The extent of the bearing area in actual contact and the corresponding unit pressure when wear ceases vary with the temperature and properties of the lubricant.

The second stage in the life of a sliding-contact bearing consists of relative motion between surfaces separated by a lubricant. If this condition persists indefinitely, the only necessary

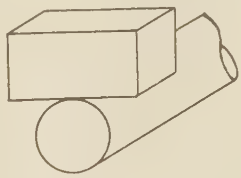


Fig. 1

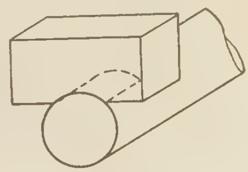


Fig. 2

quality of a bearing metal would be an ability to attract and retain lubricant on its surface. However, all bearings stop occasionally with consequent disturbance of lubrication equilibrium and restarting results in wear.

Present Design of Bearings

In this paper the term bearing metal shall apply to the part on which the major portion of wear is to take place.

At present the design of bearings considers (*a*) mechanical strength of both journal and bearing, (*b*) heat dissipation, and (*c*) wear.

An ideal bearing metal should (*a*) have sufficient mechanical strength to support the load without plastic deformation, (*b*) retain a lubricant on its surface, and (*c*) have a maximum resistance to wear without causing undue wear on the mating metal.

At present, the consideration of wear is met by using a combination of unit working pressure and lubricant that past experience has shown will not give excessive wear during continuous operation. Very little information is available on rate of wear during running-in or restarting.

Application of New Method

The new method will furnish data that will make possible a far more accurate consideration of wear. This will be accom-

plished by giving values of ultimate bearing pressure for a lubricated bearing, and relative rate of wear during running-in and restarting.

The depth of the worn volume and the revolutions of the cylinder are measured periodically. There may be computed from these readings the total travel of a point on the surface of the cylinder and the volume worn away and corresponding unit pressure. The equations to accomplish this are derived in the Appendix.

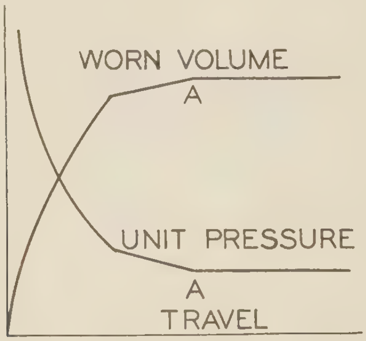
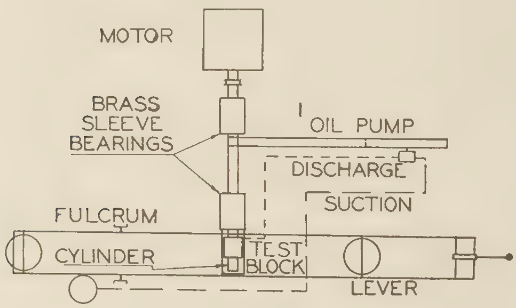
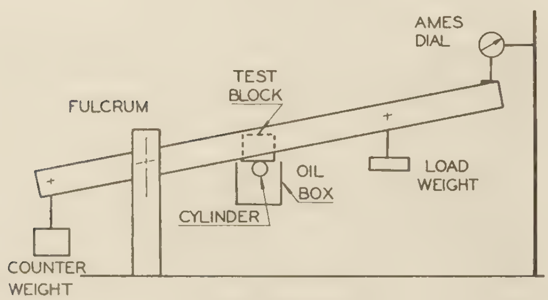


Fig. 3 Typical Curves of Worn Volume and Unit Pressure Vs. Travel



(a) Plan View



(b) Lever Mechanism

Fig. 4 Experimental Testing Machine

The curves of volume worn away and unit pressure against linear feet of travel are shown in Fig. 3. Wear ceases at A and any further running is to insure accuracy. To aid in comparing the relative performance of various metals, the test information may be simplified to one curve. This curve is obtained by plotting rate of wear against unit bearing pressure. To obtain the values of rate of wear we must measure worn volume per unit of travel for a variety of unit pressures. This work will be materially shortened if a mathematical expression can be found that will represent the data. The worn volume per unit of travel may then be obtained by taking the first derivative of the expression of worn volume with respect to travel or *d volume/d travel.*

The curve showing rate of wear for a given metal will furnish information as to the behavior of that metal during running-in and restarting. The unit pressure at which wear ceases will be the ultimate pressure for the conditions of the test. The test information so obtained is of course applicable only to the same metals, lubricant, temperatures, ratio of length to diameter, and rubbing speed. With this more definite knowledge at his command, the designer can select the most desirable combination of metals, ubricant, and physical proportions.

Description of Experimental Testing Machine

The mechanism, shown diagrammatically in Fig. 4, consists essentially of a rigid lever supported at the fulcrum and carrying the test block which in turn bears on the cylinder. This arrangement permits motion of the block of bearing metal only in a circle about the fulcrum as a center. The angle moved through is so small that for all practical purposes the block of bearing metal may be said to have straight-line motion.

In designing and constructing the lever care was exercised to meet the several limitations imposed. The fulcrum of the lever

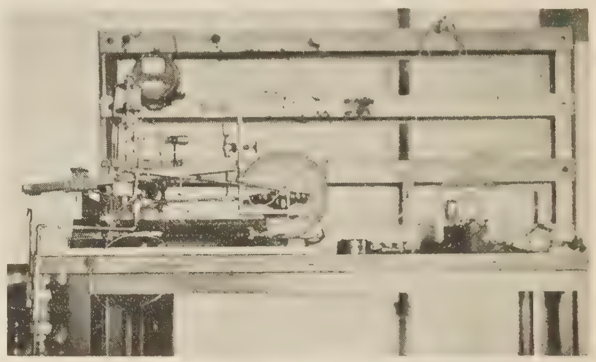


Fig. 5 Completed Experimental Testing Machine

was placed in a horizontal plane tangent to the top of the test cylinder so that the moment of the friction force would not be a disturbing element. A fulcrum consisting of hardened steel points working in conical recesses was employed so that the lever would not move in any way except about its own fulcrum. A counterbalance was provided to prevent any pressure between the test pieces due to the weight of any of the parts. A calibrated weight was hung from steel points on the lever to supply the definite known pressure between the cylinder and the block of bearing metal. The block of bearing metal was clamped securely to a holder plate which is in turn bolted to the lever with provision for adjustment in any direction between the holder plate and the lever. Fig. 5 shows a photograph of the machine as set up.

The lever serves the further purpose of magnifying the depth of worn volume, thereby improving the accuracy of reading. Various methods have been used to measure the movement of the lever as wear progressed. A 0.0001-in. Ames dial gage was found valuable for studying the early stages when the lever movement is relatively fast. For a complete test, however, a 0.0001-in. micrometer screw in conjunction with a telephone head set or a grid-glow tube is a desirable combination.

The cylinder as used in this experimental machine consists of a length of $^1/_2$-in. steel rod rigidly supported by two brass sleeve bearings mounted on the same heavy cast-iron base used for the

lever fulcrum support. One end of the steel rod was connected through a flexible coupling to a $^1/_4$-hp, 1750-rpm, ball-bearing motor. The other end of the steel rod, which constitutes the test cylinder or test journal proper, was prepared by grinding to as near a true right circular cylinder as is easily possible. The maximum variation in diameter at any cross-section was of the order of 0.0001 in.

To lubricate the test pieces a small metal box kept full of oil at a constant level was so placed that the test journal, which enters it through a felt packing, and the bearing block are completely flooded with oil. A gear pump was provided to recirculate the oil continually.

The temperature of the lubricant supplied to the bearing is measured by means of a copper-constantan thermocouple in-

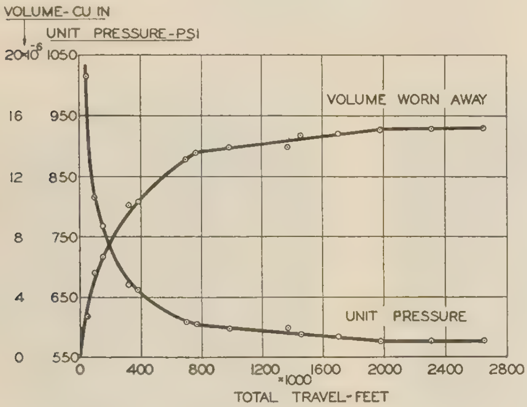


Fig. 6(a) Test Curves of Worn Volume and Unit Pressure Vs. Feet of Travel
(Meta IB; Oil A.)

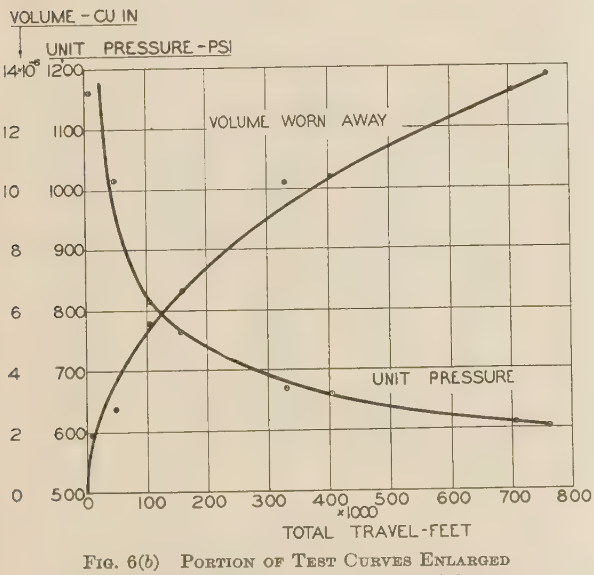


Fig. 6(b) Portion of Test Curves Enlarged
[Curves of Fig. 6(a) from 0 to 800,000 ft.]

stalled in a glass tube filled with oil. The tube rests in the box of lubricant; the glass tube electrically insulates the thermocouple from its metal surroundings.

The temperature of the block of bearing metal is measured by means of copper and a constantan wire, each peened into opposite faces of the block near the test surface. In order to reduce to a minimum the dissipation of heat from the block, asbestos paper was placed between the block and its support.

The rpm of the cylinder is obtained by measuring the slip of the motor, using a mark on the shaft and a neon lamp.

Illustrative Test

The following example will illustrate the use of the results obtained by this new method of testing.

A specimen of bearing metal is clamped in the holder described and adjusted tangent to the test journal with the aid of Prussian blue. It is not absolutely necessary that the bearing metal be exactly tangent to the cylinder provided it is approximately so. The projected area is measured at the completion of a run and if the bearing metal were not quite tangent at the beginning the projected area of the worn volume would be a trapezoid rather than a rectangle.

The time is recorded as the machine is started. At present no attempt is made to read the lever deflection at starting. When the load weight is first applied, conditions will be very unstable, probably due to a slight amount of plastic deformation. About 30 seconds after starting it is possible to obtain readings of lever deflections and these are recorded throughout the test. To furnish an idea of the length of a run it may be stated that the total time varies from two weeks to a month of continuous operation. During this period a point on the surface of the cylinder travels a distance of the order of 3,000,000 ft. After the test is complete the lever deflection readings are corrected to agree with the projected area of worn volume obtained by measurement. Other readings taken are rpm of cylinder, temperature of bearing metal, temperature of lubricant, temperature of the room, and power consumed by the driving motor.

The tabular values of data and results appear in the Appendix. Curves of total feet of travel as abscissas and unit pressure and total volume worn away as ordinates are shown in Fig. 6(a). The general shape of the curves shows quite definitely that a discontinuity occurs at about 800,000 ft of travel. Beyond this point wear takes place at a greatly reduced rate. After about 2,000,000 ft of travel, wear seems to cease altogether even though the run was continued to about 2,700,000 ft of travel. The ready location of these different phases of wear is an advantage of this type of test.

The curve of worn volume from 800,000 ft of travel on to 1,800,000 ft of travel seems to be a straight line. The part of the volume curve from 0 to 800,000 ft of travel is drawn to an enlarged scale on Fig. 6(b). After some experimentation with a log curve, a parabola, and an ellipse, the ellipse was selected as the curve most closely representing the data. The ellipse selected was of the form

$$y^2 = B^2/A^2(2Ax - x^2)$$

where y = volume worn away in cu in.
x = travel in feet
B = the semi minor axis = 0.00001840 in.
A = the semi major axis = 2,280,000 ft travel

Substituting

$$volume^2 = \frac{0.0000184^2}{2{,}280{,}000^2}(2 \times 2{,}280{,}000 \times travel - travel^2)$$

As outlined earlier in this paper the slope of this volume curve at any point represents rate of wear. The first derivative of the ellipse is

$$\frac{dy}{dx} = \frac{B^2}{A^2}\left(\frac{A - x}{y}\right)$$

or

$$\frac{d(volume)}{d(travel)} = \frac{0.00001840^2}{2{,}280{,}000^2}\left(\frac{2{,}280{,}000 - travel}{volume}\right)$$

This derived curve, evaluated for ten increments of travel from 100,000 ft of travel on, gives Fig. 7.

This curve of *d(volume)/d(travel)* plotted against the corresponding unit pressures graphically portrays the relation between rate of wear and bearing pressure for this particular metal under the conditions of the test.

The point at which wear ceases is simply determined by the pressure curve Fig. 6(*a*) dropping to a value where an oil film may be maintained. This value may be appropriately called the ultimate bearing pressure and used for design with a factor of safety.

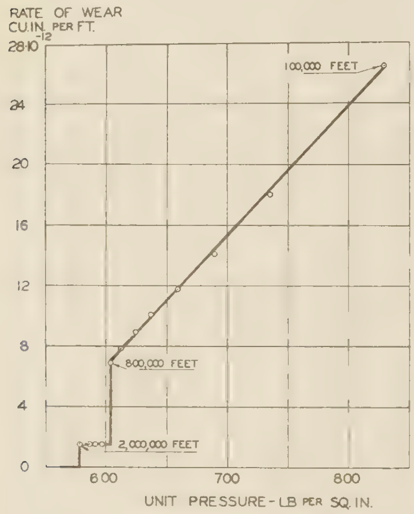


Fig. 7 Rate of Wear Vs. Unit Pressure
[Derived from curves of Fig. 6(*a*); see Table 2, Appendix.]

The pressure at which an oil film may be maintained seems to be affected by a number of variables among which are: the lubricant, the temperature of the lubricant, and the ratio L/d. The bearing metal is subject to at least two known variations: that of composition and that of crystal size which is dependent upon conditions of casting and cooling.

Fig. 8 shows two photomicrographs of the bearing-metal surface; (*a*) before the test and (*b*) after. The metal surface after the test was completed shows definitely that the crystal structure is that of a bearing in service. It is anticipated that the wear qualities of a metal will be influenced by the size and distribution of the supporting crystal.

General Use of Test

There are several problems connected with the use of bearing metals concerning which much needed information may be obtained by the test described:

(*a*) The allowable working pressure can be determined by the ultimate bearing pressure in conjunction with a factor of safety

(*b*) The amount of wear during starting of an actual bearing will be indicated by the relative position of the rate-of-wear curve

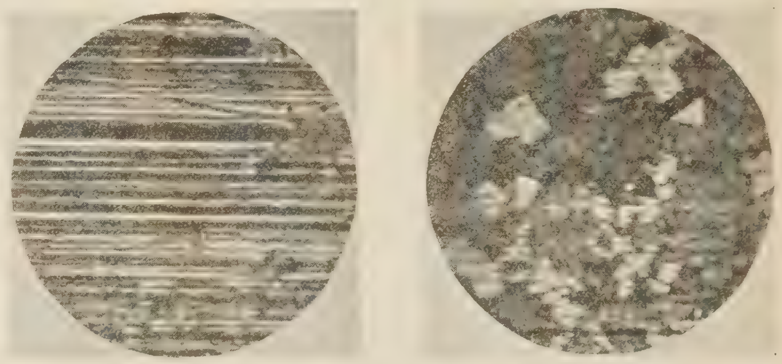
(*c*) Interrelation of the variables, for example the optimum L/d ratio, may vary with both the lubricant and the bearing metal.

The intended type of service for a given bearing will determine the relative emphasis to be placed on items *a* and *b* during design.

In order to obtain the data on which to base these selections, each one of the variables must be investigated separately.

The field of investigation into the performance of bearing metals, to which this method may be applied particularly, is broadly divided into three phases:

1. Using a certain bearing metal as a standard of comparison, the wear-reducing properties of various lubricants may be determined, together with the effect of variation in viscosity of a given lubricant
2. Using a certain lubricant as a standard of comparison, the effect of composition, crystal size, and physical proportions may be investigated
3. Using the representative lubricants and the representative metals, the interrelation of the variables may be determined.



(*a*) Before Testing (*b*) After Testing

Fig. 8 Photomicrographs of Bearing-Metal Surface

Appendix

The mathematical relationships (*a*) between the variable of projected area and readings taken during a test, and (*b*) between volume worn away and readings taken during a test are derived as follows. The use of these expressions considerably reduces the labor of working up results from data obtained.

Let P_x = any position of the face of the block

n = CD (Fig. 9), the diametral travel of P_x from its original tangent position

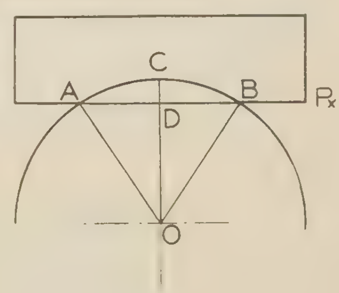


Fig. 9

w = AB (Fig. 9) the width of worn volume

L = the dimension of worn volume along the axis of the cylinder

d = the diameter of the cylinder

v = the volume worn away.

(*a*) Find w in terms of n and d.

$$w = 2AD = 2(nd - n^2)^{1/2} \ldots\ldots\ldots\ldots [1]$$

Rearranging

$$w = 2d\left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{1/2} = 2dK_1 \ldots\ldots\ldots [2]$$

where

$$K_1 = \left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{1/2} \ldots\ldots\ldots\ldots [3]$$

and the projected area

$$wL = 2LdK_1 \ldots\ldots\ldots\ldots [4]$$

(*b*) Find v in terms of n and d.

$$v = Lx \text{ (the area of the segment } ABCD) \ldots\ldots [5]$$

Substituting

$$v = Ld^2\left\{{}^1/_4 \text{ arc sin } 2\left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{1/2} - \left({}^1/_2 - \frac{n}{d}\right)\left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{1/2}\right\} \ldots\ldots [6]$$

and letting

$$K_2 = {}^1/_4 \text{ arc sin } 2\left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{1/2} - \left({}^1/_2 - \frac{n}{d}\right)\left[\frac{n}{d} - \left(\frac{n}{d}\right)^2\right]^{\frac{1}{2}} \ldots\ldots [7]$$

the worn volume

$$v = Ld^2K_2 \ldots\ldots\ldots\ldots [8]$$

The work of calculating the results of any test is very simple, requiring only a graph of K_1 and K_2 plotted against the ratio of n/d for values of n/d from 0 to 0.5. Such a set of curves is shown in Fig. 10. The curve for K_1 is the arc of a circle thus giving a check on the accuracy of those computations.

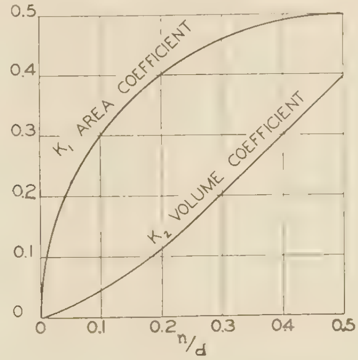


FIG. 10 AREA AND VOLUME COEFFICIENTS

Starting with the test data consisting of values of n for various times during the test, the values of K_1 and K_2 may be read off the chart and substituted in the appropriate equations. The resulting values of area and worn volume may then be used as indicated in the paper.

TABLE 2 DATA FOR RATE OF WEAR CURVE, FIG. 7

Travel, ft	Volume, cu in. × 10^5	Unit pres., lb/in.^{2}	Slope, in.^{3}/ft × 10^{12}
100,000	0.539	830	26.4
200,000	0.753	735	18.0
300,000	0.913	690	14.1
400,000	1.040	660	11.8
500,000	1.145	638	10.1
600,000	1.244	625	08.8
700,000	1.325	612	07.8
800,000	1.395	602	06.9

TABLE 1 DATA AND RESULT SHEET

Test of B metal

Average rpm = 1759; L = 0.375 in.; d = 0.492 in.; Bearing load 10.78 lb

A Time	B Deflection × 10^3	C n × 10^4	D (n/d) × 10^4	E K_1 × 100	F w × 100	G wL × 100	H p, lb/in.^{2}	J P, 1000 (lb/ft^2)	M Travel, 1000 ft	N K_2 × 10^5	P v, in.^{3} × 10^6
0.017	0.25	0.73	1.49	1.220	1.20	0.45	2390	344.0	0.23	0.28	0.25
0.033	0.40	1.18	2.40	1.575	1.55	0.58	1855	267.0	0.46	0.53	0.48
0.100	0.70	2.08	4.24	2.075	2.04	0.76	1410	203.0	1.38	1.16	1.05
0.167	0.90	2.65	5.39	2.325	2.29	0.86	1250	180.0	2.30	1.64	1.49
0.283	1.05	3.09	6.29	2.485	2.46	0.92	1170	168.0	3.91	2.00	1.81
0.533	1.10	3.24	6.60	2.515	2.48	0.93	1160	167.0	7.35	2.10	1.90
3.500	1.40	4.12	8.36	2.865	2.82	1.06	1015	146.0	48.3	3.00	2.71
7.633	2.25	6.62	13.40	3.655	3.51	1.32	816	118.0	105.5	6.20	5.61
11.416	2.45	7.22	14.70	3.825	3.76	1.41	764	110.0	158.0	7.36	6.67
24.066	3.20	9.42	19.20	4.360	4.29	1.61	669	96.2	331.0	11.20	10.20
29.10	3.25	9.51	19.50	4.410	4.34	1.63	660	95.0	403.0	11.50	10.40
51.13	3.85	11.30	23.00	4.790	4.71	1.77	610	86.6	705.0	14.64	13.20
55.40	3.95	11.60	23.60	4.850	4.77	1.79	602	86.6	764.0	15.10	13.70
71.08	4.00	11.70	23.80	4.890	4.81	1.80	597	86.0	980.0	15.50	14.00
96.11	4.00	11.70	23.80	4.890	4.81	1.80	597	86.0	1330.0	15.50	14.00
105.5	4.15	12.20	24.80	4.980	4.89	1.83	588	84.6	1458.0	16.40	14.80
120.3	4.20	12.30	25.00	5.010	4.94	1.85	582	83.7	1695.0	16.50	14.90
143.5	4.25	12.50	25.40	5.050	4.98	1.87	575	82.6	1980.0	16.90	15.30
168.2	4.25	12.50	25.40	5.050	4.98	1.87	575	82.6	2320.0	16.90	15.30
192.3	4.25	12.50	25.40	5.050	4.98	1.87	575	82.6	2655.0	16.90	15.30

EXPLANATION OF ITEMS IN TABLE 1

Col.	Explanation
A	Time elapsed
B	Deflection measured at end of lever
C	Col. B/3.41: 3.41 being the constant for lever used
D	Col. C/0.492
E	Read from chart of K_1 vs. (n/d), Fig. 10
F	$w = 2LdK_1$
G	wL
H	10.78 lb/Col. G
J	Col. H × 144
M	$\frac{0.492 \times 1759 \times 60 \text{ (hr elapsed)}}{12}$ Since the rpm of the motor was constant within the limits of experimental error the total travel of a point on the surface of the test cylinder is directly proportional to the time elapsed so that "M" follows directly from Col. A
N	Read from chart of K_2 vs. (n/d)
P	$v = Ld^2K_2$

Classification of Drying, Including Graphical Analysis of Air Drying as Developed Abroad

By A. Weisselberg,[1] Jersey City, N. J., Chas. W. Thomas,[2] New York, N. Y., and T. R. Olive,[3] New York, N. Y.

In order that the art of drying, or in other words the process of removing liquid from a mixture, may become a field of true engineering endeavor, it must be freed from the existing confusion with regard to classification and terms, and the analytical approach to the problem must be facilitated.

In this paper the authors classify the liquids as to kind, nature, and state, enumerate the means available for their removal, and discuss briefly the limitations of the various drying methods with regard to the material being processed and the results obtained.

A graphical method of analyzing air drying, the most widely used drying process, is described by the authors, and by means of this analysis, terms which are now confusing are defined and factors governing the performance of drying equipment are explained.

Drying is usually defined as the partial or complete removal of evaporable liquids from a mixture of the liquid with solids, other liquids, or gases. To be more specific, the definition should include the words "by thermal means," i.e., by supplying or removing heat. Thus we differentiate it from the other category of moisture removal, wherein this end is accomplished by mechanical means and is commonly designated as dehydration. Desiccation has been suggested as an appropriate technical term that would embrace both methods of moisture removal.

Kind, Nature, and State of Liquid

As to liquids, we distinguish between two groups: (*a*) pure liquids, and (*b*) solutions. Pure liquids are classified as (*a*1) water and (*a*2) liquids other than water, commonly known as solvents. Liquids which undergo a change in state by chemical action do not belong here, even though the term "drying" is applied to the process which accomplishes this change in state. Oils which harden by oxidation exemplify such liquids, and the use of the term "drying" in this case is altogether out of place.

Solutions are either (*b*1) crystalloidal or (*b*2) colloidal. The former are readily diffusible and are also characterized by the fact that, at the same temperature, their vapor pressures are lower than those of the pure liquids of which they are composed. Colloidal solutions, on the other hand, diffuse with difficulty, but their vapor pressures are hardly affected by the presence of the colloids. The difference in these properties will, obviously, influence the removal of moisture, as will later be seen.

It is assumed that when we dry or dehydrate, the state of the material from which the liquid is removed does not change, or, in other words, we deal with the removal of free moisture as distinguished from the moisture of crystallization and that of decrepitation. The last is really free moisture mechanically entrapped within certain crystals. Its removal precludes the retention of the crystal form and the crackling noise by which the removal is accompanied warns of the approaching danger of complete disintegration into powder form into which the crystals fall when the moisture of crystallization is driven out. The removal of the moisture of crystallization is called calcination and is beyond the scope of this paper.

The free moisture with which we are concerned may be found present in one of the following four states: surface moisture, capillary moisture, cellular moisture, and as vapor.

Means of Removing Moisture

Evidently, removal of moisture by mechanical means is confined to extraction of moisture without changing the state of the moisture, since any change of state implies that heat must be supplied or removed. This limits dehydration to surface and capillary moisture, while moisture in any of the four states mentioned may be removed by drying. Thus arises the question as to when one method should be used in preference to the other as far as the removal of surface or capillary moisture is concerned. Aside from the fact that the removal of large percentages of moisture is always accomplished with greater efficiency by dehydration, the choice of the method may also be governed by the desired result. Thus, if the liquid carries salts in solution, the presence of which is undesirable in the final product, dehydration to the lowest possible moisture content must be resorted to. On the other hand, just the opposite result may be desired, since, for instance, the salts in solution may have a nutritive value, in which case preference will be given to drying.

---

[1] Consulting Mechanical Engineer. Jun. A.S.M.E. Mr. Weisselberg received his engineering diploma from the Technical University of Vienna, Austria. He came to the United States in 1923 and, after a diversified practise in various engineering fields, established himself in 1930 as a consulting engineer. He is the author of a number of articles published in recent years on the subject of air-conditioning and drying and has modified and introduced in this country the Mollier water-air mixture chart reproduced in this paper.

[2] Consulting Engineer. Mem. A.S.M.E. Mr. Thomas was graduated from the Stevens Institute of Technology with the degree of mechanical engineer in 1884 and after graduation became assistant superintendent of the Dixon Pencil Works, Jersey City, N. J. He has had a wide experience in the development, design, and construction of machinery for inventors and has lectured in machine design at the Newark Evening Technical School and at Columbia University. Mr. Thomas retired recently from the staff of the university as professor of machine design and has entered into consulting practise, specializing in the dehydration of food products. He is chairman of the Drying Committee of the Process Division, A.S.M.E.

[3] Associate Editor, *Chemical and Metallurgical Engineering*. Jun. A.S.M.E. Mr. Olive was graduated in 1923 with the degree of A.B. from Harvard University, where he specialized in the field of engineering sciences, with special reference to mechanical and chemical engineering. After graduation he spent a number of years in the employ of several chemical companies, including the National Aniline & Chemical Co. and the DuPont Rayon Co. Since 1927 he has been a member of the editorial staff of *Chemical & Metallurgical Engineering*, of which he is now associate editor. He is the author of numerous articles on various phases of chemical engineering, coauthor of the chapter on process control in Perry's Chemical Engineers' Handbook, and secretary of the Process Industries Division, A.S.M.E.

Contributed by the Process Industries Division and presented at the Metropolitan Section Meeting, New York, N. Y., October 18, 1932, of The American Society of Mechanical Engineers.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

Thus, either method may be used alone, or both in combination, depending upon the end to be accomplished. A knowledge of both methods is required, therefore, when the problem of moisture removal is to be dealt with.

Dehydration is accomplished by subjecting the mixture to pressure and providing a resistance for the retention of one of the ingredients. In this operation we differentiate between (*a*) pressure applied directly, compressing the mixture to a smaller volume, as in pressing or squeezing, and (*b*) pressure applied indirectly, without compressing the mixture to a smaller volume,

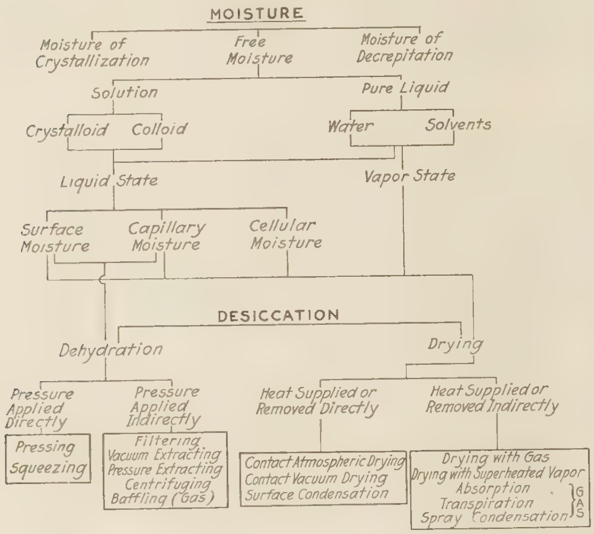


Fig. 1 Removal of Moisture From Air or Gas

as in filtering, vacuum extracting, centrifuging, pressure extracting, and baffling, the latter applying to gases.

As already stated, drying deals with the removal of moisture by thermal means. Heat is supplied or removed in order to change the liquid from one state to another, thus accomplishing separation. If the moisture is in vapor state, as is the case in drying a gas, the vapor must be reduced to the liquid state by removing the latent heat of vaporization. The reverse is true if the original state of the moisture was liquid.

With respect to the manner in which the heat is applied, we distinguish between (*a*) heat supplied or removed directly by a medium other than the one carrying the moisture away (contact drying), and (*b*) heat supplied or removed indirectly by the same medium which carries the moisture away (air drying).

With method (*a*) of applying heat, if the moisture must be removed at low temperature, or quickly, or without exposure to the oxidizing action of the atmosphere, vacuum drying will be resorted to as distinguished from atmospheric drying in which the vapors are discharged into the surrounding atmosphere. In this category there also belongs the drying of a gas by condensing the vapors by passing the gas over cooled surfaces.

With method (*b*) of applying heat the use of air as a drying medium is the most common practise. If the product to be dried is subject to oxidation, an inert gas or products of combustion will be used instead of air. The ability of superheated steam to evaporate moisture also falls into this group. On the face of it, its use in connection with drying at high temperatures (above 212 F) looks rather advantageous from the point of view of thermal efficiency. Actually, the efficiency would not be higher than with air drying at sufficiently high temperatures and saturation, inasmuch as, with the approach of the boiling temperature, the heat consumed in heating the air becomes negligible. On the other hand, the power consumption would be materially greater with superheated-steam drying, since a greater volume would have to be moved per pound of moisture removed than with air drying. This, together with other difficulties which this practise involves, makes the use of superheated steam for drying of little practical value, except when other conditions call for it.

The removal of vapor moisture from air or gas by indirect removal of heat may be accomplished by absorption through chemical reagents or by adsorption through adsorbent materials, by transpiration through hygroscopic fibrous material, or by precipitation through spray condensation. Fig. 1 shows this at-

TABLE 1 FACTORS WHICH INFLUENCE DRYING CONDITIONS AND THEIR LIMITATIONS

Factors	Limitations			
	Physical	Chemical	Biological	Market Requirements
Final moisture content.	Optimum for maximum strength. Not too low if soaking ability be not destroyed. Low if grindability is a factor.	Not too low to avoid discoloration. Low if by reabsorption of moisture product will melt.	Below hygroscopic point if growth of bacteria be prevented.	Low to lower freight cost. Not lower than regain at average air condition. 1/4 of hygroscopic point if powdered or granular, as these tend to pack in storage. Very low if bitter aromatics must be driven out.
Temperature.	Low if strength is affected. Low if there is danger of melting. Low if change in shape is objectionable.	Low if danger of disintegration. Low if danger of decomposing acids. Low if danger of chemical discoloration. Low if coagulation of albumen is to be avoided to retain solubility. Low if sublimation of valuable volatiles be prevented.	Low if vitamin A and C should be retained. High if germs or bacteria be destroyed.	High to improve taste by production of desirable aromas.
Drying time.	Short if soaking ability be high. Long if there is danger of distortion, case - hardening, cracking.	Short if the damaging effect of high temperatures as listed above is to be offset.	Short if damaging effect of high temperature on vitamins be offset. Short to prevent growth of bacteria if present. Short to conserve aromatic oils if present.	Long if desired uniformity is not otherwise obtainable.
Drying medium.	Cleaned if impurities in drying medium damage the surface of the dried product.	Non-oxidizing if there is danger of oxidation.	Non-oxidizing to prevent promotion of destruction of vitamins A and C. Cleansed and filtered if danger of contamination from bacteria in air.	....
Handling.	Careful to prevent objectionable physical damage. Without tension to prevent objectionable lowering of strength by not allowing for shrinkage.	Preventing contact with materials that would cause objectionable chemical contamination.	....	Careful if appearance is stressed.

tempted classification in chart form. Obviously it cannot claim perfection and criticism is invited.

It appears desirable to carry the classification further to the factors which influence the drying conditions with respect to certain limiting requirements. These factors are: (1) final moisture content, (2) temperature, (3) drying time, (4) drying medium, and (5) the way the product is being handled in the course of moisture removal. The limitations which may have to be considered in connection with these factors may be grouped as follows: (a) physical limitations, (b) chemical limitations, (c) biological limitations, and (d) marketing-requirements limitations. This classification will cover almost any condition that may have to be considered as shown in Table 1, for which completeness cannot be claimed.

Definitions of Terms

It is of greater importance, however, to discuss the definitions of the principal terms used in connection with drying, about some of which there seems to exist considerable confusion.[4] These are as follows:

Moisture Content. The desirability of expressing the moisture content in per cent by weight of the dry material is often still not fully realized. Moisture contents are still very often given on a wet basis and sometimes the basis is not given at all. Expressed on a dry basis a change in percentage tells directly the change in moisture by weight per pound of dry material. It may be well, however, to use a shorter expression such as "dry-basis moisture" instead of "moisture content on a dry basis."

Capacity. If M designates the quantity of dry material expressed in any unit of measure (lb, yd, etc.) that the drying equipment holds at one time, and τ the time the material must remain in the drier to dry to the required moisture content, then M/τ is the "production capacity" per unit length of time. M is the holding capacity, and τ the drying time. For any one drier, the holding capacity is the same, but the drying time will vary in accordance with a number of factors.

Drying Time. If w represents the drying rate in pound of moisture removed per square foot of total drying area of material A per hour and Y_1, Y_2, the initial and final "dry-basis moisture" of the material, respectively, then the drying time τ equals $\frac{M\ (Y_1 - Y_2)}{wA}$; i.e., it is inversely proportional to the drying rate. As long as the wet product still has surface moisture, one may expect that the rate of removal of moisture will not differ from that of the evaporation of a film of liquid. The drying rate accordingly will be equal to the rate of evaporation. After the surface moisture is gone, however, the capillary moisture will begin to diffuse to the surface and two different cases become possible.

In the first, the possible diffusion rate per unit area is at first greater than the rate of evaporation for the same area. Then we can assume that the moisture will overflow the end of the capillaries at the surface and keep the surface partially or totally wet, depending upon the nature of the surface and the nature of the liquid. The drying rate will remain the same, or drop, according to the extent of wet-surface reduction. This will continue until the diffusion rate per unit area of total surface becomes equal to the drying rate or, in other words, until the diffusion rate per unit area of wet surface equals the evaporation rate. Sherwood[5] calls the period during which the rate of diffusion exceeds the rate of evaporation the zone of unsaturated surface drying, assuming that during this period the amount of wet surface gradually becomes less, which does not necessarily hold true for all cases. When the rate of diffusion falls below the rate of evaporation for the same unit area, the diffusion rate alone controls the rate of drying.

As a second case the diffusion rate per unit evaporation area is lower than the evaporation rate. The surface will then dry out unless the drying conditions are changed in such a manner as to make the evaporation rate equal to the diffusion rate. In other words, the drying rate must be equal to or lower than the diffusion rate.

Suppose that the drying conditions are so maintained that the evaporation rate per unit of wet area is greater than the diffusion rate for the same area. Then the surface will dry and the plane of evaporation will retreat somewhat from the surface. With the same drying conditions the rate of evaporation in this plane will be lower because of the much increased resistance to heat transfer through the dry layer. On the other hand, the rate of diffusion for this plane is greater than for the surface. Hence, the plane of evaporation would not have to retreat very far before subsequent stages of equilibrium are reached. The result, however, will be the undesirable condition of a dried surface enveloping the wet interior and a considerable drop in drying rate. In general, then, depending upon the initial and final moisture content, the average drying rate and, in turn, the drying time will be a function of either the evaporation rate or the diffusion rate, or both.

Evaporation. Evaporation is essentially a heat-consuming process. In terms of sensible heat transfer, the rate of evaporation in pounds of moisture per square foot per hour is expressed by the general equation $\frac{U(t_a - t_l)}{h_v - h_l}$ in which U stands for the overall heat-transfer coefficient in Btu per square foot per hour per degree F, $(t_a - t_l)$ for the temperature difference between heating medium and liquid to be evaporated, and $(h_v - h_l)$ for the difference in heat content between vapor and liquid, i.e., the latent heat of vaporization.

We may also express the rate of evaporation in terms of vapor heat transfer, by the equation $\frac{L(p_l - p_v)}{h_v - h_l}$ in which L, the vapor, heat-transfer coefficient, stands for Btu in the vapor diffused per inch of mercury per square foot per hour and p_l and p_v the vapor pressure of the liquid at temperature t_l and the partial pressure of the vapor, respectively. Substituting K for $\frac{L}{h_v - h_l}$, the evaporation rate can also be set equal to $K(p_l - p_v)$, K being the mass transfer coefficient in pounds per square foot per hour per inch of mercury pressure difference.

Another way of expressing the rate of evaporation in case the heat for evaporation is supplied only by the air was introduced by Lewis[6] under the assumption that $U(t_a - t_l) = r(X_s - X_a)k'$, r being the latent heat of vaporization at wet-bulb temperature, X_s and X_a, respectively, the absolute humidities at saturation and of the air, and k', a coefficient of vapor diffusion in pounds of moisture per square foot per hour per unit absolute humidity difference. On this assumption $k' = U/s$, s being the specific heat of the humid air (defined by Grosvenor as humid heat) since $(X_s - X_a)r = s(t_a - t_l)$. However Schmidt[7] has shown that $k' = \frac{U}{s} \times \frac{\kappa}{\alpha}$, wherein κ stands for the mass diffusivity constant and α for the thermal diffusivity. For evaporation of water

[4] "Fundamentals of Drying Methods," by C. W. Thomas and A. Weisselberg, presented at the 1933 Annual Meeting of the A.S.M.E. This paper covered definitions of terms employed in classifying drying methods and equipment.

[5] "The Drying of Solids," by T. K. Sherwood, *Ind. Eng. Chem.*, vol. 21, 1929, p. 12 and p. 976, also vol. 22, 1930, p. 132.

[6] "Evaporation of a Liquid Into a Gas," by W. K. Lewis, Trans. A.S.M.E., vol. 44, 1922, p. 325.

[7] *Chemische Fabrik*, vol. 29, 1929, p. 527.

into air κ/α was determined at 1.09, which is close enough to unity to make the Lewis formula usable for practical purposes. We see, therefore, that we may express the rate of evaporation in four different ways. Values for all four coefficients, U, K, L, and k', are available from a great deal of experimental data. Results with values for still air check fairly well. For moving air, the values given as functions of velocity and turbulence lead in many instances to quite different answers.

If the heat for evaporation is derived only from the air the liquid assumes the wet-bulb temperature t_s. The rate of evaporation is therefore proportional to the temperature difference $(t_a - t_s)$ termed the wet-bulb depression. According to the foregoing it is also proportional to the partial pressure difference $(p_s - p_a)$, p_s being the vapor pressure at saturation corre-

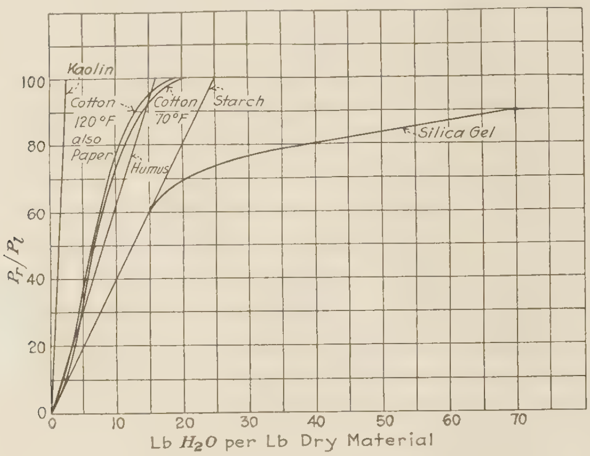


Fig. 2 Regain Curves for Various Materials

sponding to the wet-bulb temperature. The term drying potential for $(p_s - p_a)$ is quite appropriate because it signifies the drying potentiality of the air. In contact drying with the heat for evaporation supplied from an outside source, the heat may be supplied at such a rate that t_l exceeds the boiling point of the liquid, i.e., the temperature at which the vapor pressure is equal to the total pressure p of the air above the liquid. In this case, the evaporation rate depends on the overall heat-transfer rate from heating medium to liquid and the available temperature drop. However, if the temperature of the liquid is lower than the boiling point the rate of evaporation will be controlled by the rate of diffusion of the vapor into the surrounding medium at the existing pressure drop $(p_l - p_v)$. Unless the rate of heat flow from heating medium to liquid is checked to suit the rate of diffusion, the temperature of the liquid will rise to a level at which equilibrium exists.

In connection with evaporation, there still remains to be discussed the hygroscopic moisture and its evaporation. In the beginning it was mentioned that the vapor pressure of crystalloidal solutions is lower than the vapor pressure of the pure liquid at the same temperature. As an extreme example, a saturated soda-ash solution boils at 572 F. This corresponds to a pressure of 1227 lb per sq in. Most organic materials contain, in their cells, both crystalloidal and colloidal solutions. As the moisture content decreases, the concentration of these solutions increases, especially that of the crystalloid solution, since, as stated, it diffuses readily. With the increase in concentration a point is reached when the vapor pressure becomes sensibly affected. This is called the hygroscopic point. If p_r denotes the reduced pressure and p_l the pressure of the pure liquid at the same temperature, then p_r/p_l will decrease as the moisture content decreases. This relation for various materials is shown in Fig. 2. Substituting the reduced pressure, p_r for p_l, in the evaporation formula, $(p_r - p_v)$ must be positive if evaporation is to take place. If p_r, corresponding to a certain moisture content, is equal to p_v, no more moisture can evaporate. Hence each moisture content below the hygroscopic point is associated with a drying potential equal to the reduction in pressure $(p_l - p_r)$, which is the same as saying that the equilibrium moisture content is a function of the drying potential or of the wet-bulb depression of the drying air. Hygroscopic moisture-content curves (regain curves), which have been published for various substances, show the moisture content plotted against the relative humidity of the air at a certain temperature. From the foregoing, it appears more logical, although admittedly less convenient, to plot the hygroscopic moisture content against the wet-bulb depression or the drying potential and present the relation independently of the temperature. Even those inorganic materials which themselves do not go into crystalloidal solution with the liquid they contain may be hygroscopic if they contain salts as impurities which will go into solution with the liquid. Common salt, for instance, is only slightly hygroscopic, but it contains magnesium salts which make it very hygroscopic. It is for this reason that, in order to obtain a non-hygroscopic salt, the mother liquor should be removed by dehydration as far as possible.

As the air picks up moisture, its drying potential decreases. The average rate of evaporation is equal to the logarithmic mean of the initial and final rates of evaporation, and is found directly by using the logarithmic mean for $(t_a - t_s)$, $(p_s - p_v)$, and $(X_s - X_a)$, respectively, in the given formulas for evaporation.

Diffusion. Compared with evaporation, the mechanism of diffusion is much more complicated, especially when no outside force is applied, the difference of concentration of liquid being the only driving force that causes the liquid to flow. This force diminishes and changes with the location. Like all problems of this nature in which the rate of flow of a quantitative substance changes with the time and location, the relation is expressed by a differential equation of the second order. In the case of liquid diffusion in a body, it is assumed with sufficiently close approximation that the rate of propagation of concentration of liquid K, in pounds per foot per hour per unit of concentration, is constant. Then the flow μ of the substance in the direction x is equal to $-\kappa' \dfrac{d\sigma}{dx}$, σ denoting the concentration. The change of the concentration with the time will be proportional to change in flow along X, or $\dfrac{d\sigma}{d\theta} = \dfrac{d\mu}{dx} = \dfrac{\kappa' d^2\sigma}{dx^2}$. The integration of even this equation, let alone those in which we would have to consider diffusion in three directions and with variable κ', is extremely difficult to solve. Of interest to practical engineers are only the curves and tables worked out by physicists[8] of which the latest and most complete ones are those by Prof. Albert B. Newman.[9] With their help the results of laboratory tests can be interpreted for practical purposes, and where coefficients are known, the change of moisture content with the time for bodies of certain geometrical shape may be determined under varying conditions of initial moisture distribution. Although there are admittedly practical drying problems to which this information may be applied directly, it must be borne in mind that the solutions are based on constant conditions, such as constant temperature of the material and constant flow, and constant temperature and

[8] Williamson and Adams, *Phys. Rev.*, vol. 14, 1919, p. 39; Lederer, *Zeitschrift für Angew. Chem.*, 1924, pp. 370–750; Sherwood, *Ind. Eng. Chem.*, vol. 21, 1929, p. 12; Peck, *Phys. Rev.*, 1930, p. 35; Newman, *Cooper Union Bulletin*, no. 5, 1932.

[9] *Cooper Union Bulletin*, no. 5, 1932.

humidity of the air. Not only are these seldom encountered, but we should actually change them in order that we may improve on nature, so to speak.

The question arises whether we should let the difference of concentration of liquid be the only force to drive the moisture out, and whether we cannot apply an outside source of energy to speed up diffusion. How this is accomplished in contact drying does not require further explanation. But from it we may recall the fact that the moisture diffuses in the direction of vapor-pressure drop, and where there is vapor-pressure drop there must be temperature drop. Hence, in the case of air drying, if we do not want to depend upon "natural diffusion," we must maintain a temperature drop from the center of the body to the surface. We may do this continuously or intermittently, in both cases utilizing the heat of the air for this purpose. In the latter case, we will have alternating periods during one of which the heat input, $U(t_a - t_l)$, will be greater than the heat in the steam evaporated, $L(p_l - p_v)$, while during the other it will be equal or lower. On the other hand, during the period of drying, which would otherwise be controlled by the diffusion, we may so adjust conditions by changing U, which it should be recalled is a function of air velocity and turbulence, that $U(t_a - t_l)$ will always be somewhat greater than $L(p_l - p_v)$, the difference being utilized to cause "forced diffusion" at a rate corresponding to $\frac{L(p_l - p_v)}{p}$. Obviously, because of the change that occurs in the rate of forced diffusion with reduced moisture content, $U(t_a - t_l)$ and $L(p_l - p_v)$ must also be changed to suit. The calculations for the proper determination of the variables are rather cumbersome. A graphical solution suggested by Prof. E. Schmidt[10] quite simplifies the problem.

In connection with diffusion there is also to be considered the effect of the capillaries and the cells upon it. Undoubtedly, if the surface of evaporation is at right angles to the capillaries, the flow of moisture to the surface will be assisted by the capillary force. As soon as the moisture surrounding the cells becomes less, the cell moisture will diffuse into the capillaries, whence the capillary force will assist it to the surface. No reference is known of investigations which take these questions into account. The fact that the moisture in the cells has crystalloids and colloids in solution, only adds to the complication. From what we said in the beginning, one may anticipate that in the case of a crystalloidal solution, the entire solution will diffuse to the surface, where the salts will be left behind after the moisture has evapo-

[10] Föppl Festschrift, Springer Verlag, Berlin, 1924.

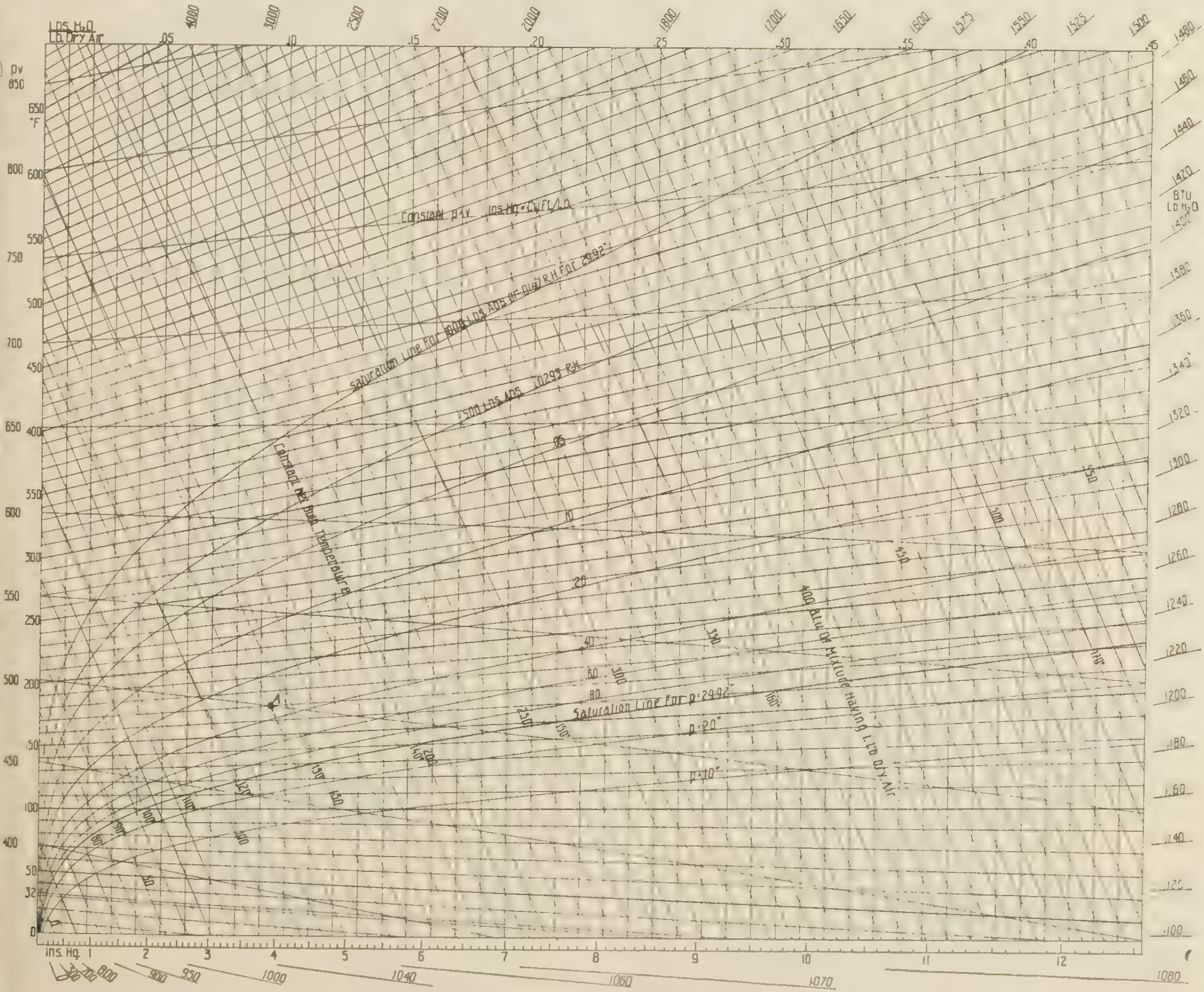


FIG. 3 WATER-AIR MIXTURE CHART
(Based on: lb mol H_2O/lb mol air = 0.622; C_p air at 100 F = 0.2420; C_p air at 700 F = 0.2460; C_p H_2O obtained from Keenan steam tables.)

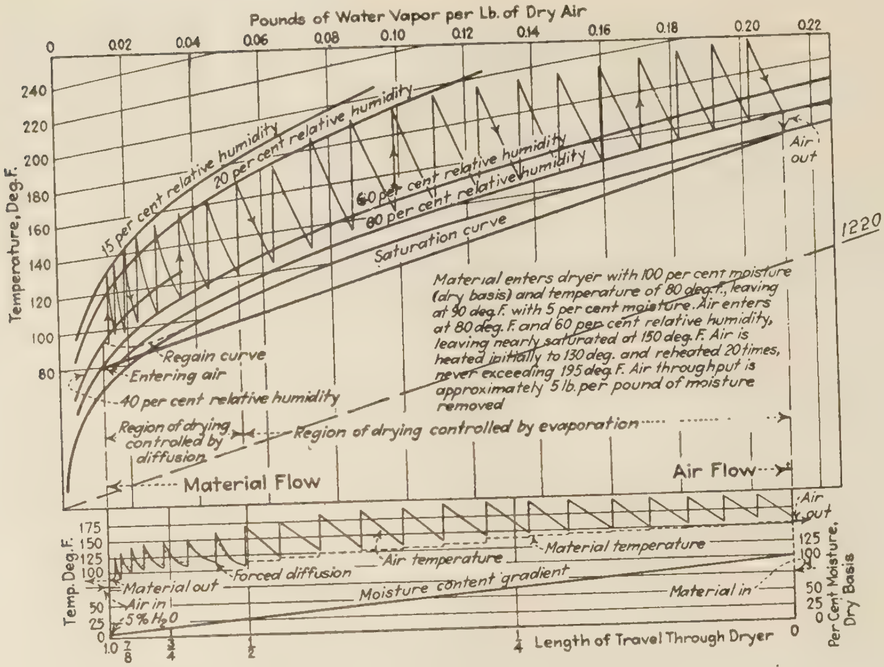


Fig. 4 Performance of a Counterflow Reheating Air Drier Shown on a Skeleton Mollier Water-Air Mixture Chart

(Air and material temperatures and moisture gradient of material are shown in lower diagram.)

rated. In the case of a colloidal solution in the cells, only the moisture will diffuse, leaving the colloids behind on the inside walls of the cells.

Efficiency. The amount of air that passes through the drier for the evaporation of a certain quantity of moisture is a direct function of the difference in humidities X_i and X_o, respectively, of the air going into and coming out of the drier. In a continuous drier, the rate of flow expressed in pounds of dry air per hour, d_f, is equal to $\dfrac{w}{X_o - X_i}$. The power P_f required to move this quantity of air through the drier is only part of the air power needed in an efficient drier employing recirculation. The

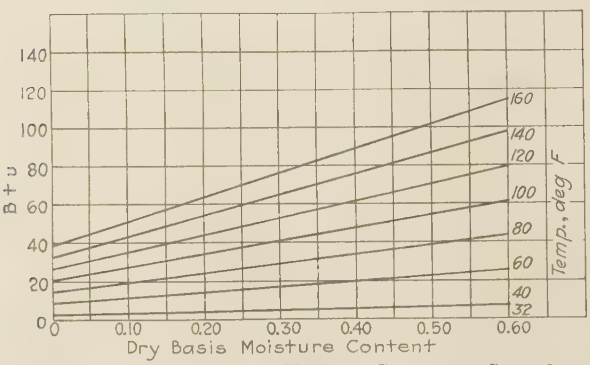


Fig. 5 Water-Material Mixture Chart for $C_p = 3$

balance P_r is required to recirculate the air at a rate d_r, which can be approximately determined as follows: If q is the total thermal transmission in Btu per hour and t, the average temperature rise of the air passing through the heaters at a considered air velocity, then $n = \dfrac{q}{d_f\left(1 + \dfrac{X_o - X_i}{2}\right) s\,\Delta t}$, the number of times d_f must be circulated per hour and $d_r = d_f\left(1 + \dfrac{X_o - X_i}{2}\right) n/\rho$, the rate at which the air is recirculated in cubic feet per hour, if ρ is the average density of the air in the drier. The temperature rise Δt of the air passing through the heater in each section of the drier must correspond to the temperature drop from evaporation in that section of the drier. The efficiency of the drier expressed in terms of air horsepower, therefore, will depend a great deal upon the design of the drier with respect to the distribution of heating surface and the resistance to flow of air to and from the heaters. At the expense of increased air horsepower a continuous drier employing reheating may attain the same thermal efficiency as a similar drier of superior design. For the purpose of comparison of performance, therefore, one should know both heat and power consumption per pound of moisture removed. The investigation

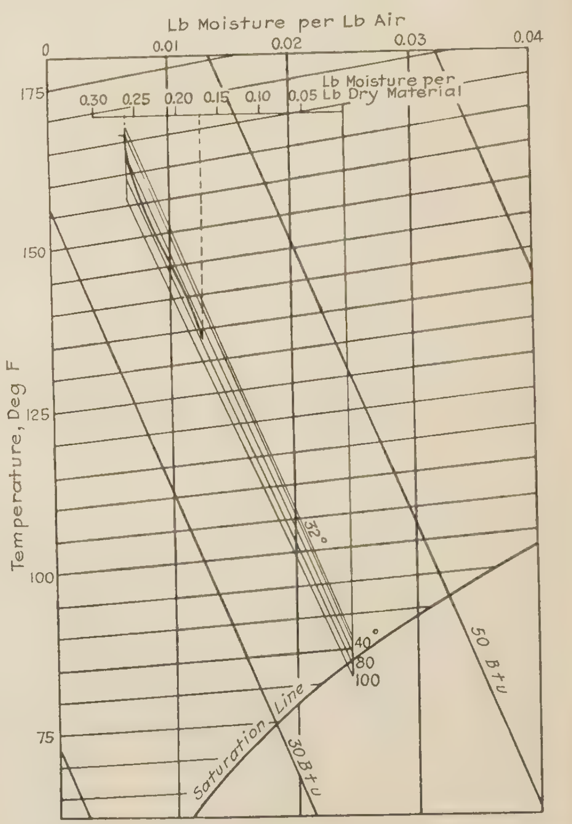


Fig. 6 Water-Material Mixture Chart ($C_p = 3$) Superimposed on Water-Air Mixture Chart

should also include a heat balance in which the heat input appears in the following items:

(1) Heat to evaporate the moisture at the temperature at which it enters the drier
(2) Heat to raise the temperature of the evaporated moisture from the temperature at which the moisture enters the drier to the temperature of the exit air
(3) Heat to raise the temperature of the air entering the drier to the exit temperature, including its initial vapor content but not including the moisture added in the course of the drying process
(4) Heat carried from the drier with the material (including final moisture content) above the temperature at which it enters the drier
(5) Heat loss due to radiation and convection from the inclosure.

Graphical Analysis of Drying Process

Graphical presentation facilitates the analysis of a process. For drying, two principal charts are needed, one a liquid-gas mixture chart in which the change of condition of the air or gas may be shown, the other a liquid-material mixture chart for presenting the change of condition of material. For each kind of liquid and gas, and liquid and material, a different chart has to be drawn. A chart for water and air is shown in Fig. 3 and is based on Professor Mollier's suggestion to use heat content and moisture content as coordinates and set these coordinates at an angle. A most useful chart is thus obtained. Referring to it and assuming an atmospheric pressure condition of 29.92 in., point *A* indicates a dry-bulb temperature of 170 F (left end scale), a wet-bulb temperature of 128 F (constant wet-bulb line), a partial pressure of 3.9 in. Hg (bottom scale), a dew-point temperature of 124 F (intersection of vertical with saturation line), a humidity of 0.0935 (top scale), a percentage humidity of $\frac{0.0935}{0.428} = 0.2185$ (ratio of moisture content to saturated moisture content on top scale), a relative humidity of $\frac{3.9}{12.2} = 0.32$ (ratio of partial pressure to saturated pressure at same temperature, on bottom scale), a heat content of 140 Btu, a specific volume per lb of mixture of $\frac{500}{29.92} = 16.7 \left(\frac{\text{constant } pv}{29.92}\right)$. The marginal scale at top, bottom, and right-hand side points toward the origin (0 F) and the slope of the connecting lines indicate Btu per lb of moisture added per pound of dry air if the air changes in a direction parallel to this slope. Thus, for instance, in Fig. 4, the line connecting the initial and final state of the air is parallel to the 1220 Btu line, indicating the Btu consumed per pound of moisture removed per pound dry air. All the above readings may be made relative to any other pressure within the range of the chart. Furthermore, adiabatic compression (vertical) may be followed on the chart if the compression ratio to the 1.4 power is taken from tables or calculated.[11] Fig. 5 shows a water-pulp mixture chart. The specific heat for the pulp is 0.3. Hirsch[12] suggests superimposing the one chart upon the other as shown in Fig. 6. For a drying process of a simple nature this may be practical, but when reheating stages with changing quantities of air are used, the procedure becomes too involved to be practical.

[11] The application of this chart to the graphical treatment of the so-called "Oxford drying process" was presented in a paper by A. Weisselberg at a meeting of the Metropolitan Section of the A.S.M.E., April 18, 1933.

[12] "Die Trokentechnik," by Hirsch, Springer Verlag, 1932.

IN TWO SECTIONS—SECTION TWO

TRANSACTIONS

of The American Society of Mechanical Engineers

RECORD AND INDEX

[The first instalment of the 1934 Record and Index, pages RI-1 to RI-30 (Committee Personnel and Memorial Notices) was issued as Section 2 of the Transactions for August, 1934, and the second instalment, pages RI-31 to RI-58 (Annual Reports of the Council and Committees) as Section 2 of the Transactions for November, 1934]

JANUARY, 1935

VOL. 57, NO. 1

Published by The American Society of Mechanical Engineers

TRANSACTIONS

of The American Society of Mechanical Engineers

Published on the tenth of every month, except March, June, September, and December

Publication Office, 20th and Northampton Streets, Easton, Pa.
Editorial Department at the Headquarters of the Society, 29 West Thirty-Ninth Street, New York, N. Y.

Includes Aeronautical Engineering

Entered as second-class matter March 2, 1928, at the Post Office at Easton, Pa., under the act of August 24, 1912. Price $1.50 a copy, $12.00 a year; to members and affiliates, $1.00 a copy, $7.50 a year. Changes of address must be received two weeks before they are to be effective on our mailing list. Please send old, as well as new, address.

The Engineer and Recovery—The Challenge to the Mechanical Engineer

By PAUL DOTY

THE American Society of Mechanical Engineers is vitally interested in any rational program for national recovery from the stagnation of depreciated values which have blighted national prosperity during the past five years.

The Society, in contradistinction to other professional engineering societies, has been termed the Society of the Industries, and its work is primarily with the durable-goods industries rather than with the consumer-goods industries.

It is recognized that the consumer-goods industries are operating at practically normal capacities. What is needed, therefore, is to restore the purchase and use of durable goods, where the purchase and use is now at a low ebb.

The mechanical engineer is professionally interested in aeronautics, fuels, hydraulics, iron and steel, machine-shop practise, management of industries, materials-handling, oil and gas power, petroleum, power equipment, printing industries, railroads, textile machinery, wood industries, and process plants.

Any national recovery program which will stimulate these professional divisions and activities, and put men and women back at work at their normal occupations, and restore prosperity to the durable-goods industries and to the nation, is assured of the interest of the mechanical engineer.

To the engineer work means the overcoming of resistance, and if there be resistance to any program of national recovery, therein is the challenge to the engineer to carry the program to success.

What will the mechanical engineer offer through the professional divisions toward national recovery? In aeronautics, engines now make possible air flights of four hundred miles per hour with safety, and a speed of six hundred miles per hour is now contemplated. If speed will annihilate distance and save time, the engine to do the required work will be forthcoming.

Aeronautical Engineering

Aeronautics has been moving forward by leaps and bounds, as best illustrated, perhaps, by the recent England-to-Australia race. Great attention has been attracted in this race by the performance of the DeHaviland *Comet* which made the crossing in 72 hr of total time, more than 18 hr ahead of its nearest competitor. A more careful analysis of the race, however, shows that the second place, with a time of little more than over 90 hr, and the third place with a little longer time, were taken by American-built planes of the transcontinental-liner type carrying passengers and mail, and permitting regular commercial operation, while the *Comet* was a specially built racing plane.

Heretofore there have been only two makes of airplanes of the unconventional design; one, the pterodactyl, having no tail; and the autogiro, maintaining itself in the air by means of a "windmill" rather than a lifting component acting on stationary wings.

The inventor of the autogiro, de la Cierva, started with wingless planes, relying entirely on the windmill for lift. This design later was departed from, wings of a restricted capacity being introduced. Recently, however, because of a better knowledge of the mechanism and principles of operation of the windmill, de la Cierva has gone back to his original design and has dispensed with the wings, producing an airplane capable of flying at a speed closely approaching an average man's run.

Unquestioned progress is being achieved in two other directions. Florine, in France, appears to be approaching a practical solution of the helicopter problem and is apparently in line for building a helicopter that will fly. Whether there is room for such a machine in competition with other types of aircraft remains, of course, to be seen.

In another field, that of creating a machine dispensing with the use of the propeller and employing its wings both as a lifting and a propulsion medium, progress is being made by several designers, most of whom are working along the line of rotating sets of wings by means of a special mechanism so that the axes of the wings follow a path approaching a cycloidal curve. If any of these machines (such as Chapdelaine, Strandgren, etc.) are ever fully developed, they will be capable of flying both forward and backward. This will bring the safety of flying to approximately the same level as the safety of automobiling, with corresponding increase in the use of aerial transportation.

Fuels and Power

In fuels the engineer sees a form of energy which may be converted into light, heat, and power, whether the fuel be solid, liquid, or gaseous. The conversion efficiency factor is the work of the engineer. The conservation of energy is the field of the engineer.

Progress in the use of pulverized coal has been made, not only in the method of application but in better comprehension of the theory of combustion of that fuel, in the selection of suitable types of fuel, and in the development of burners and machinery for the preparation of the coal.

Pulverized coal was first introduced in water-tube boilers. It has now, particularly in Great Britain, been successfully applied also to Lancashire boilers. This, it is said, has opened a wide field for the application of pulverized coal when burned at the mouth of the mine, where, for various reasons, water-tube boilers are not always considered to be suitable.

National wealth is national prosperity. The potential water powers of the nation may become a source of national wealth with the application of hydraulic turbines.

In addition to the water there are the air currents. The attempt to develop power from the wind at the experimental plant in New Jersey apparently has not yet reached the stage where a public announcement can be made. In The Netherlands and in Russia, aerodynamic principles have been applied to the design of windmills, with the result that new types have been introduced which can operate on much lower wind speeds and are, therefore, capable of working practically 24 hours a day.

The comprehension of the process of combustion of Diesel-engine fuels has led to a grading of these fuels by ignitibility, showing the little suspected fact that the very characteristics which make a fuel especially suitable for engines such as are used in motor cars, make it undesirable for Diesel engines.

In power equipment and generation progress has been made

Presidential address delivered at the Annual Meeting, New York, N. Y., Dec. 3 to 7, 1934, of The American Society of Mechanical Engineers.

along several lines, one by increasing the size of units, which reduces the first cost per unit of capacity and the maintenance cost by requiring fewer crews. It may be that the limit for present equipment has been about reached. Another direction is to increase automaticity of the plant and thus decrease operating costs without sacrificing efficiency. A third direction in which there is promise of progress is in the creation of entirely new sources of power, such as from atomic energy. This, however, is as yet only in the earliest stages of laboratory development.

Materials of Engineering

Progress has been made in the field of engineering materials. The so-called stainless or rustless steels, when tested under service conditions, were found to be corrodible, though to a very much lesser extent, of course, than plain steels. This condition is now fairly well understood, with the result that the conditions under which high-chromium steels do not stand up have been determined. Moreover, by the application of such additional materials as titanium, the intergranular corrosion of these steels has been inhibited and their field of usefulness greatly extended.

Progress likewise has been made in tungsten carbide cutting materials. These have shown amazing capacities for performance on certain materials, such as cast iron, and at first failed on other materials, for example, steel, where they produced "cratering," leaving the machined surface very rough. Tantalum carbide cutting materials are not made by melting the constituents and casting them, but by preparing them in the form of a very fine powder and then sintering them under great pressure. This is due to the fact that, heretofore, no way of melting these extremely refractory materials has been found that would not destroy the carbide constituent. The manufacture of tungsten carbide cutters has led to the development of the technique of powder metallurgy and this is having its applications in several new fields.

Production of surface hardness in soft steel by means of nitriding is, of course, well known. Lately, however, methods have been developed to apply it to iron castings made in sand and permanent molds, giving a very hard surface with the usual internal formation of cast iron.

A spectacular achievement in the field of engineering materials, however, is the use of beryllium in copper alloys, which apparently promises the solution of an age-old problem of making a copper alloy that will be as subject to hardening through heat-treatment as is steel. From present indications beryllium plays the same rôle in copper alloys, though not in the same proportions, as carbon does in steel.

Because of its application to the manufacture of springs and the promise of large demand if employed extensively for copper-hardenable alloys, great effort is being made to reduce the cost of the manufacture of beryllium both in this country and in Germany. There is no lack of raw materials for this manufacture.

Welding

In the field of welding one of the spectacular achievements has been the introduction of shot-welding, in which unusually large current densities under accurate control are employed. This has permitted the construction of railway cars of a lower weight than apparently would have been otherwise possible.

The application of welding first made on an extensive scale some years ago on the German pocket battleship *Ersatz-Preussen* has now been introduced in this country, cutting down the weight per horsepower surprisingly, i.e., from 45, and in some cases, 60 lb to less than 20 lb.

Management and Production

In the domain of the engineer lies the technique of production. Organizing for work will always be a fruitful field for engineering endeavor and is needed today as never before. The hard years of the depression have taught us much about waste and inefficiency, and the technique we have learned will find abundant opportunity for constructive use as soon as factories begin to pick up their accustomed loads. This skill will be particularly necessary in the reconstruction period, when much must be regained with the expenditure of little. What Taylor and Gantt taught us of management, and what thousands of their followers have since developed, is quite as useful to an impoverished industry as the skill of its artizans, or the desire of the world for its products. These things lie at the very basis of engineering philosophy, and have furnished the reasons for the promotion of engineers into managerial posts.

With cheap and abundant power, and with our growing knowledge of chemistry and metallurgy, much progress has been made lately in materials. Examples of large and important industries based on such developments are evidence of the further impetus to recovery that can be given by engineers. Every new material of importance establishes a new industry and the basis for new articles and techniques. If it comes into competition with better known materials it forces advances in their technology, providing more opportunities for the services of engineers, and more jobs for workers. We can fight economic stagnation and defeatism by technological progress in these and allied lines.

Railroads

In railroads the use of alloy steels and light-weight materials have cut down weights in newest trains. Sweeping changes in standard railroad equipment may be made as a result of the recent successful use of these materials in high-speed railway transportation. This is believed to indicate a definite swing to the use of lighter, but stronger, metal in constructing equipment.

Nine high-speed trains are now under construction in various shops. Three of these are being built of stainless steel; three of high-tensile, corrosion-resisting steel; one of high-tensile steel and aluminum; and two are being built entirely of aluminum.

Replacement of obsolete or worn-out equipment has long been one of the most pressing problems of railroad executives. Estimates were recently made of the number of properly conditioned locomotives now available for use on the larger railroads which indicate that should there be an increase of 15 per cent in traffic, the carriers would have to call out every engine fit for use to meet the need.

Modern locomotives are now of such efficient types that it is claimed they will pay for themselves in five years, and dividends which now go up in smoke may be reclaimed by the substitution of modern locomotives. The growth of air-conditioning has provided a stimulant for recovery and machinery for improving passenger travel.

Industrial Reconditioning

There is a governmental agency whose purpose is to stimulate the flow of private funds through private lending institutions into several kinds of building construction.

The engineer knows the great importance of renovation and modernization. While for the moment the Federal Housing Administration and the Home Owners' Loan Corporation are bending their energies toward home reconditioning, it is believed a rare opportunity exists to coordinate home reconditioning with industrial reconditioning. Fortunately, industries appreciate the necessity of keeping their properties in 100 per cent condition,

for in addition to expenditures for current maintenance and repair, which are operating expenses, a provision is made for depreciation reserves for reconditioning. It may be said that the depreciation reserves are not always kept in the treasury of the industries as cash, but are used for other purposes incident to the needs of the industries. To do the work of reconditioning now may require the use of private credit, and, fortunately, private credit is available at low interest rates. In former depressions, the courageous investor was successful in taking advantage of low interest rates to buy when money was cheap, and property correspondingly below normal value. History will repeat itself. Not only is private credit available, but a governmental agency in the Reconstruction Finance Corporation will provide a supplementary source of credit.

The Supreme Court of the United States has recently given a decision of much importance as related to the practise of depreciation charges against earnings, and the Treasury Department has revised its regulations for allowable deductions in income tax returns for depreciation. It is distinctly to the advantage of industries to incur expenditures for the use of depreciation reserves for modernization.

It is believed there are at least three billions of dollars of industrial depreciation reserves which can be expended for new and improved equipment at the present time. Many examples can be given of the growth and amount of depreciation reserves in industry, and the important thing to remember is that now is the time to do this work, when it can be done to the best advantage, and to the benefit of the nation. To give value to these expenditures is the challenge to the engineer, and particularly the mechanical engineer as the engineer of industry.

Human Needs Still Exist

Analysis shows that consumer-goods industries are not unduly depressed, and that is understandable, for consumer goods have worn out in the past five years and must be replaced of necessity. The unemployed are found in the capital-goods industries, and if we wait until the capital goods wear out before we begin replacement we shall have a long time to wait. It is distinctly to the credit of industry currently to set up depreciation reserves against the possible loss of property life, and to assume that they are payable on the death of the property, but rather are they not premiums to maintain the life of the property in good health and in 100 per cent condition of usefulness. Industry will not die while human needs exist. Human needs follow the growth of population and with an increase in population in excess of five millions in the past five years, the nation is not at a standstill. Nature has bountifully supplied for the sustenance of human needs. The engineer provides the machinery for the comforts of living.

The engineer has an understanding of the materials of nature, and the forces of nature to be applied for the benefit of mankind. May it not be added that there is an understanding of the laws of nature, and if it be true that "self-preservation is the first law of nature," will not the use of depreciation reserves be an example of self-preservation, and the application of a natural law to recovery?

If it be true that "self-preservation is the first law of nature" it may be added that "habit is nature's second law." It is getting to be a habit to call for a New Deal. This is true not only in industry but in our social relations. Not only must we meet the problems of Society Engineering, but we are face to face with the New Deal in social engineering and nature's law. May we not say natural laws are dictated by conscience and are discerned by right reason? "The pursuit of life, liberty and happiness" is cited from the Declaration of Independence as an expression of a natural law. It is generally accepted that human nature is still in the saddle, and unsound public economy is an evidence of the weakness of human nature. I believe that in our political economic relations nature's laws are against communism and in favor of private property on the ground of watchfulness and attention which self-interest produces in the conduct of business, for that is natural. In return for the use of private property for the public good, due compensation must of necessity be provided.

The Challenge to the Engineer

Engineers realize that there is a scientific method of approach in acquiring systematic knowledge. We believe there are two types of approach—the technical and the logical. Whereas we know by the evidence of sight the ultimate agency for which *machinery* is intended, the ultimate agency for the *machinery of nature* is concealed from sight; but is it not the work of the engineer and scientist to rise from the visible to the invisible—from what we observe by sense to what we know by reason?

The mechanical engineer will reestablish himself as the producer of wealth, the enemy of waste and inefficiency, the labor saver, the skilled operator of the machinery of modern living, the manager of industrial enterprises, and the provider of jobs and opportunity. He will prove the falseness of accusations that make him responsible for the world's ills by upsetting its economic and social balance, and he will overwhelm the defeatists who rank security above opportunity. This he will do by making opportunity more alluring than security.

The Society's Part

As a Society we have set our financial house in order, a necessary prelude to any economic recovery. We have been engaged in a searching study of our objectives, our organization, and our program, with the intention of giving greater effectiveness to our work as a professional society. We have extended our relations with the engineering schools and have thus provided an easier approach to the engineering profession for the younger man, and a more sympathetic and closer contact with him. In cooperation with others we have established and are at present actively supporting the Engineers' Council for Professional Development, a coordination of organized effects to assume a higher type of professional engineer, and to secure for the engineer a better educational approach to his profession and an individual status economically and socially more desirable. We have helped to sustain the important activities of the American Engineering Council, which is the established embassy of engineering at Washington.

These thoughts have been designed to provoke in the minds of engineers a sense of the ungrasped opportunities that lie ahead and to provide inspiration for effective participation in national recovery. They call for supporting evidence that this Society and others similar to it in purpose are engaged in activities directed toward the end suggested. Such evidence will be found in the technical papers being presented at this meeting, and in the reports of progress prepared by our Professional Divisions. Summaries of these papers and reports cannot be attempted here. Further evidence is to be found in the constant work of our technical committees engaged in establishing industrial standards, in formulating codes of practise, testing, construction and safety, and in the stimulation of technological progress by our research groups.

The message I bring to you is one of faith in the profession of engineering. Is there waste in industry? Depend upon the engineer to make the analysis and the study to eliminate waste in industry. Are profits going to waste in smoke? Depend upon the engineer to reduce this waste. The engineer believes

in society and cooperation. The American Society of Mechanical Engineers is evidence of this belief. Here we give freely of our time and our talents for the greatest good to the greatest number. The engineer has met and is meeting the challenge of usefulness for the benefit of mankind.

Believing in cooperation, the mechanical engineer challenges the courageous leaders of industry and appeals to the far-sighted investor of faith to take advantage now of the far-reaching possibilities of industrial reconditioning as a means of recovery of national welfare.

Depositories for A.S.M.E. Transactions in the United States

BOUND copies of the complete Transactions of The American Society of Mechanical Engineers will be found in the libraries in the United States and other countries which are listed on the following pages.

Alabama

Auburn.......... Engineering Library, Alabama Poly. Inst.
Birmingham...... Public Library

Arkansas

Fayetteville...... Engineering Library, Arkansas University

California

Berkeley......... Library, University of California
Long Beach...... Public Library
Los Angeles...... Public Library
University of Southern California
Oakland......... Oakland City Library
Teachers' Professional Library
Pasadena........ Library, California Institute of Technology
Santa Clara...... Library, University of Santa Clara
San Diego........ Public Library
San Francisco.... Public Library (Civic Center)
Engineers Club of San Francisco
Mechanics Institute
Stanford Univ.... Library, Stanford University

Colorado

Boulder.......... Library, University of Colorado
Denver.......... Public Library
Fort Collins...... Colorado State Agricultural College

Connecticut

Bridgeport....... Public Library
Hartford......... Public Library
New Haven...... Public Library and Yale University
Waterbury....... Silas Bronson Library

Delaware

Newark.......... University of Delaware
Wilmington...... Wilmington Free Institute

District of Columbia

Washington...... Scientific Library, U. S. Patent Office
Library of Congress
Bureau of Standards Library
George Washington University
Catholic University

Florida

Gainesville....... University of Florida
Jacksonville...... Free Public Library
Miami........... Public Library
Tampa.......... Public Library

Georgia

Atlanta.......... Carnegie Public Library
Georgia School of Technology
Savannah........ Public Library

Idaho

Moscow.......... University of Idaho

Illinois

Chicago.......... John Crerar Library
Western Society of Engineers
Lewis Institute of Technology
Library, Armour Institute of Technology
Public Library of Chicago
Moline........... Public Library
Urbana.......... University of Illinois

Indiana

Evansville........ Public Library
Fort Wayne...... Public Library
Indianapolis...... Public Library and Indiana State Library
Notre Dame...... Library, University of Notre Dame
Terre Haute...... Rose Polytechnic Institute
West Lafayette... Library, Purdue University

Iowa

Ames............ Iowa State College
Des Moines...... Public Library
Iowa City........ State University of Iowa

Kansas

Kansas City...... Public Library, Huron Park
Lawrence........ Library, University of Kansas
Manhattan....... Kansas State Agricultural College
Wichita.......... Wichita City Library

Kentucky

Lexington........ University of Kentucky
Louisville........ Speed Scientific School
University of Louisville

Louisiana

Baton Rouge..... Louisiana State University
New Orleans..... Howard Memorial Library
Louisiana Engineering Society
Public Library
Tulane University

Maine

Orono........... University of Maine

Maryland

Annapolis........ United States Naval Academy
Baltimore........ Johns Hopkins University
Engineers Club of Baltimore
Public Library

Massachusetts

Boston........... Northeastern University
Boston Public Library
Cambridge....... Harvard University (Engineering Library)
Massachusetts Institute of Technology
Fall River........ Public Library
Lowell........... Lowell Textile Institute
Lynn............ Free Public Library
New Bedford..... Free Public Library
Springfield....... Springfield City Library
Tufts College..... Tufts College
Worcester........ Worcester Polytechnic Institute
Free Public Library

Michigan

Ann Arbor....... University of Michigan
Detroit.......... Public Library
Cass Technical High School
Highland Park Public Library
University of Detroit
East Lansing..... Michigan State College
Flint............ Public Library
Grand Rapids.... Public Library
Houghton........ Michigan College of Mining & Technology
Jackson.......... Public Library

Minnesota

Duluth.......... Public Library
Minneapolis...... University of Minnesota
Minneapolis Public Library (Engineering and Circulating Libraries)
St. Paul.......... James Jerome Hill Reference Library

Mississippi

State College..... Mississippi State College

Missouri

Columbia........ University of Missouri
Kansas City...... Public Library
Rolla............ Missouri School of Mines and Metallurgy
St. Louis......... Engineers Club of St. Louis
Public Library
Washington University
Mercantile Library

Montana

Bozeman........ Montana State College

Nebraska

Lincoln..........University of Nebraska
Omaha..........Public Library

Nevada

Reno............University of Nevada Library

New Hampshire

Durham.........University of New Hampshire

New Jersey

Bayonne.........Free Public Library
Camden.........Free Public Library
Elizabeth........Free Public Library
Hoboken.........Stevens Institute of Technology
Jersey City.......Free Public Library
Newark..........Newark College of Engineering
Free Public Library
New Brunswick...Rutgers University
Paterson.........Free Public Library
Princeton........Princeton University
Trenton..........Free Public Library

New York

Albany..........New York State Library
Brooklyn.........Polytechnic Institute
Pratt Institute
Brooklyn Public Library
Buffalo..........The Grosvenor Library
Engineering Society of Buffalo
Buffalo Public Library
Ithaca...........Cornell University
Jamaica, L. I.....Queens Borough Public Library
New York........Engineering Societies Library
Public Library
College of the City of New York
Cooper Union
Columbia University
New York Museum of Science and Industry
New York University Library
Potsdam.........Clarkson College of Technology
Rochester........Rochester Engineering Society
Schenectady......Union College
Syracuse.........Syracuse University
Public Library
Troy............Rensselaer Polytechnic Institute
Utica............Public Library
Yonkers.........Public Library

North Carolina

Chapel Hill.......University of North Carolina (Engineering Library)
Raleigh..........North Carolina State College

North Dakota

Fargo...........North Dakota State Agricultural College
Grand Forks.....University of North Dakota

Ohio

Ada.............Ohio Northern University
Akron...........Public Library
University of Akron
Canton..........Public Library
Cincinnati........University of Cincinnati
Public Library
Engineers Club of Cincinnati
Cleveland........Public Library
Case School of Applied Science
Cleveland Engineering Society
Columbus........State of Ohio Library
Public Library
Ohio State University
Dayton...........Engineers Club of Dayton
Toledo...........Public Library
University of Toledo
Youngstown......Public Library

Oklahoma

Norman..........Oklahoma University
Oklahoma City...Public Library
Stillwater........Oklahoma Agricultural and Mechanical College
Tulsa...........Public Library

Oregon

Corvallis.........Oregon State Agricultural College
Portland.........Portland Library Association

Pennsylvania

Allentown........Free Library
Bethlehem.......Lehigh University
Easton..........Public Library
Lafayette College
Erie.............Public Library
Lewisburg........Bucknell University
Philadelphia......Engineers Club
Drexel Institute
University of Pennsylvania
Franklin Institute
Pittsburgh.......University of Pittsburgh
Engineers' Society of Western Pennsylvania
Carnegie Institute of Technology
Carnegie Library (Schenley Park)
Carnegie Free Library of Allegheny
Reading.........Public Library
Scranton.........Public Library
State College.....Pennsylvania State College
Swarthmore......Swarthmore College
Villanova........Villanova College
Wilkes-Barre.....Public Library

Rhode Island

Kingston.........Rhode Island State College
Providence.......Brown University
Providence Engineering Society
Public Library

South Carolina

Clemson College..Library, Clemson College

Tennessee

Kingsport........Public Library
Knoxville........University of Tennessee
Memphis.........Goodwin Institute
Nashville........Vanderbilt University

Texas

Austin...........University of Texas
College Station...Agricultural & Mechanical College of Texas
Dallas...........Public Library
Southern Methodist University
El Paso..........Public Library
Forth Worth.....Carnegie Public Library
Houston.........Rice Institute
Public Library
Lubbock.........Texas Technological College (School of Engineering)
San Antonio......Carnegie Library

Utah

Salt Lake City...University of Utah
Public Library

Vermont

Burlington.......University of Vermont

Virginia

Blacksburg.......Virginia Polytechnic Institute
Charlottesville....University of Virginia
Norfolk..........Public Library
Richmond........Virginia State Library

Washington

Pullman.........State College of Washington
Seattle...........Public Library
Engineers Club
University of Washington
Spokane.........Public Library
Tacoma..........Public Library

West Virginia

Morgantown.....West Virginia University

Wisconsin

Madison.........Library, University of Wisconsin
Milwaukee.......Public Library
Board of Industrial Education, Vocational School Library
Marquette University

Wyoming

Laramie.........Wyoming University

Depositories for A.S.M.E. Transactions Outside the United States

Argentine

Buenos Aires.....Biblioteca de la Sociedad Cientifica

Australia

Adelaide.........Public Library of Adelaide
Melbourne.......Public Library of Victoria
Perth............University of Western Australia Library
Sydney..........Public Library, N. S. W., Sydney

Belgium

Louvain........University of Louvain

Brazil

Rio de Janeiro....Bibliotheca da Escola Polytechnica
Bibliotheca Nacional
Sao Paulo........Bibliotheca da Escola Polytechnica

Canada

Montreal.........McGill University
Engineering Institute of Canada
Toronto..........University of Toronto, Library

Chile

Santiago.........Universidad de Chile, Facultad de Ciencias Fisicas y Matematicas (Engrg. School)

Cuba

Havana..........Cuban Society of Engineers

Czechoslovakia

Prague...........Masarykova Akademie Prace
Society of Czechoslovak Engineers

Danzig Free City........Bibliothek der Technischen Hochschule

Denmark

Copenhagen......The Royal Technical College

England

Birmingham......Birmingham Public Libraries
Bristol ....University of Bristol
Cambridge.......University of Cambridge
Leeds...........University of Leeds
Liverpool........Public Library of Liverpool
Liverpool Engineering Society
London..........City & Guild Engineering College
Institution of Automobile Engineers
Institution of Mechanical Engineers
Institution of Civil Engineers
Institution of Electrical Engineers
The Junior Institution of Engineers
The Royal Aeronautical Society
Manchester......Manchester Public Libraries (Reference Library)
Oxford...........University of Oxford
Newcastle-upon-Tyne..........The North East Coast Institution of Engineers and Shipbuilders
Sheffield.........Sheffield Public Libraries

Wales

Cardiff...........Cardiff Public Library

France

Lyons...........University of Lyons
Paris............École Nationale des Arts et Metiers
École Nationale Supérieure de L'Aeronautique
École Centrale des Arts et Manufactures de Paris
Société des Ingénieurs Civils de France

Germany

Berlin..........Verein deutscher Ingenieure
Bibliothek der Technischen Hochschule
Breslau..........Bibliothek der Technischen Hochschule
Cologne (Köln)...Universitäts- und Stadtbibliothek
Dresden.........Bibliothek der Technischen Hochschule
Düsseldorf.......Bücherei des Vereines deutscher Eisenhüttenleute

Germany (continued)

Frankfort........Technische Zentralbibliothek
Hamburg........Bibliothek der Technischen Staatslehranstalten
Hanover.........Bibliothek der Technischen Hochschule
Karlsruhe........Bibliothek der Technischen Hochschule
Leipsic..........Stadtbibliothek
Munich..........Bibliothek der Technischen Hochschule
Bibliothek des Deutschen Museums
Stuttgart........Bibliothek der Technischen Hochschule

Hawaii

Honolulu.........University of Hawaii Library

Holland

Amsterdam.......Koninklijke Akademie von Wetenschappen
Delft............Bibliotheek der Technische Hoogeschool
The Hague.......Koninklijk Instituut van Ingenieurs
Rotterdam.......Nationaal Technisch Scheepvaartkundig Institut

India

Bangalore........Mysore Engineers Association
Calcutta.........Bengal Engineering College
Poona...........Poona College of Engineering
Rangoon.........University of Rangoon

Ireland

Belfast. ....Queen's University of Belfast

Italy

Milan...........Biblioteca della R. Scuola d'Ingegneria
Comitato Autonomo per l'Esame della Invenzioni
Naples...........Biblioteca della R. Scuola d'Ingegneria
Rome ....Biblioteca della R. Scuola d'Ingegneria
Consiglio Nazionale delle Ricerche presso il Ministero della Educazione Nazionale
Turin............Biblioteca della R. Scuola d'Ingegneria

Japan

Kobe............Kobe Technical College
Tokyo...........Imperial University Library
The Society of Mechanical Engineers
Yokohama.......Library of Yokohama

Mexico

Mexico City......Asociacion de Ingenieros y Arquitectos de Mexico
Library of the Escuela de Ingenieros Mecanicos y Electricistas

Norway

Oslo.............Den Polytekniske Forening

Poland

Warsaw..........Bibljoteka Publicazna

Porto Rico

Mayaguez........University of Porto Rico

Portugal

Lisbon...........Institute Superior Technico

Roumania

Bucharest........Scoala Polytechnica din Bucharest

Scotland

Glasgow.........Royal Technical College
Mitchell Library

South Africa

Cape Town.......University of Cape Town
Johannesburg.....South African Institute of Engineers

Sweden

Stockholm.......Kungl. Tekniska Hogskolan
Svenska Teknologföreninger
Gothenburg......Chalmers Tekniska Institut

Switzerland

Zurich............Eidgenossische Technische Hochschule

Turkey

Istanbul ....Robert College

U.S.S.R.

Kharkov.........Supreme Economic Council of Ukraine
Leningrad........Leningrad Polytechnic Institute
Moscow..........Supreme Council of National Economy
Tomsk...........Tomsk Polytechnic Institute

Ten Years of Stoker Development at Hudson Avenue

By JOHN M. DRISCOLL[1] and W. H. SPERR,[2] BROOKLYN, N. Y.

Hudson Avenue Station is a stoker-fired generating station of 770,000-kw rated capacity. The station was started in 1922 with 14-retort underfeed stokers of 355 sq ft projected grate and ashpit area and completed in 1932 with an installation of 15-retort stokers of 694 sq ft projected grate and ashpit area. Development of the rated station capacity requires that the latter installation of stokers burn coal at the rate of about 65 lb per sq ft per hr, using eastern semi-bituminous coal of about 14,000 Btu per lb as fired. On test, coal was burned at the rate of 75 lb per sq ft per hr for 48 consecutive hours, at a steam-generating-unit efficiency of 77 per cent.

The development of the various stoker units, of which there are five different types, is described and illustrated in this paper. This station was the location of the development by the Westinghouse Company of the first "link-grate" stoker, which was successfully applied here in a 15-retort design having a projected grate and ashpit area of 524 sq ft.

The 1932 installation of American Engineering Company's Taylor stokers is equipped with manual zoned-air control, which divides the air supplied to the grate section into 69 separately controlled zones. These stokers are the longest single-ended underfeed stokers on record, measuring 26 ft 7 in. from front furnace wall to the rear of ashpit.

The various steps in the development of the underfeed stokers to obtain the desired capacities are described, and an apparent limitation in capacity of a purely underfeed stoker of any considerable length is discussed.

This paper discusses also the unburned-gas losses and the cinder losses in the heat balance of a boiler-stoker test. The cinder loss attains considerable magnitude in stoker operation at high-burning rates, and loss data are given for a number of stoker tests at coal-burning rates up to 75 lb per sq ft per hr.

The extent of improvement in efficiency in stoker operation over the period of ten years due to stoker design and associated equipment is discussed from the standpoint of the installations in this particular station, efficiency data being given in curve form for the various stoker installations.

It is the hope of the authors in presenting this paper that it will serve steam-plant designers as a basis of facts on efficiency and capacity possibilities of large stoker-fired installations in the present state of the art.

A companion paper by Messrs. Hardie and Cooper, of the Brooklyn Edison Company, entitled "The Test Performance of Hudson Avenue's Most Recent Steam Generating Units"[3] presents test data and describes the test procedure and methods.

When the design of Hudson Avenue Station was initiated in 1922, underfeed stokers were the outstanding means available for burning a high-grade bituminous coal used by a steam-generating station located in the Middle Atlantic states. Subsequent to the original installation of twelve stokers at Hudson Avenue when the later additions of capacity were being provided, pulverized-fuel equipment was seriously considered because by then it had been developed so that its reliability was no longer questioned. However, after considering such factors as layout, operation, and investment costs, stokers were chosen consistently as the better method of fuel firing at Hudson Avenue.

Because of the large increase in size of each successive unit, it was necessary on each installation to utilize stokers which were longer than any in use at the time of their selection. The results of this design, from the standpoint of station investment cost and operating economy, have been very satisfactory.

Stoker Development

The station structure was built in two stages, the original building providing for three 50,000-kw turbines and three rows of boilers with stokers which went into operation in May, June, and October, 1924. The first two units were engineered and installed at the same time. The designers and operators, in order to obtain comparative operating data between two of the stokers which were on a parity on the basis of a comparison of bids, recommended the purchase of two Combustion Engineering Company's Frederick stokers, and six Westinghouse stokers. The Combustion stokers are 14-retort, 31-tuyère units with a projected grate area of 380 sq ft and a length of 15 ft 6 in. while the Westinghouse stokers are 14-retort, 27-tuyère units with a projected grate area of 355 sq ft and a projected length of 14 ft 5 in. including ashpit. The third unit was engineered during the installation of the first two, and the stokers selected were four Frederick units of the same size and design as the two purchased for No. 1 unit. The first three turbine and boiler installations were all of the same size, and the design data required a coal-burning rate of more than 50 lb per sq ft per hr to carry full station turbine capacity with eleven of twelve boilers in service. The coal-burning-rate guarantees on the first three units are tabulated in Table 1.

Since the station was designed with exceptionally high stacks,

[1] Plant Equipment Engineer, Brooklyn Edison Co., Inc. Jun. A.S.M.E. Mr. Driscoll received the degree of B.S. in mechanical engineering in 1925 from Brown University. He was employed by the Brooklyn Edison Co., Inc., in 1925, in the mechanical engineering department and has been connected with the mechanical design work of Hudson Avenue Station since that time. Since 1929 he has been plant equipment engineer.

[2] Assistant Plant Equipment Engineer, Brooklyn Edison Co., Inc. Mr. Sperr received the degree of M.E. from Stevens Institute of Technology in 1925. He was employed by the Brooklyn Edison Co., Inc., in 1925, as a cadet engineer. Since 1927 he has been with the plant-equipment bureau and in 1930 was made assistant plant equipment engineer.

Contributed by the Fuels Division and presented at the Annual Meeting, New York, N. Y., December 3 to 7, 1934, of The American Society of Mechanical Engineers.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until April 10, 1935, for publication in a later issue of Transactions.

Note: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

[3] See A.S.M.E. Transactions, November, 1934, paper FSP-56-15.

TABLE 1

Unit	Combustion rate, lb per sq ft per hr Continuous	Four hours	Two hours
No. 1 Frederick	51.6	..	62.5
Nos. 1 and 2 Westinghouse	57.0	..	73.0
No. 3 Frederick	55.2	71.0	..

it was hoped to attain the required boiler outputs on natural draft, and consequently no induced-draft fans were installed for this first section. Unfortunately, the draft proved insufficient to carry the stokers much above 45 lb per sq ft per hr so that their

The efficiency, as determined on test of Westinghouse stokered boiler No. 14 (the fourth boiler in No. 1 row), is shown at the left of Fig. 3, plotted against boiler output in millions of Btu per hour.

In 1924, load growth was still continuing at a rate which indicated the need for capacity above that of the first three units. Engineering studies made at the time indicated the advisability of raising the operating pressure of the station from 265 lb per sq in. to 400 lb per sq in. for improved economy of operation. When this was done it was also decided to install an 80,000-kw

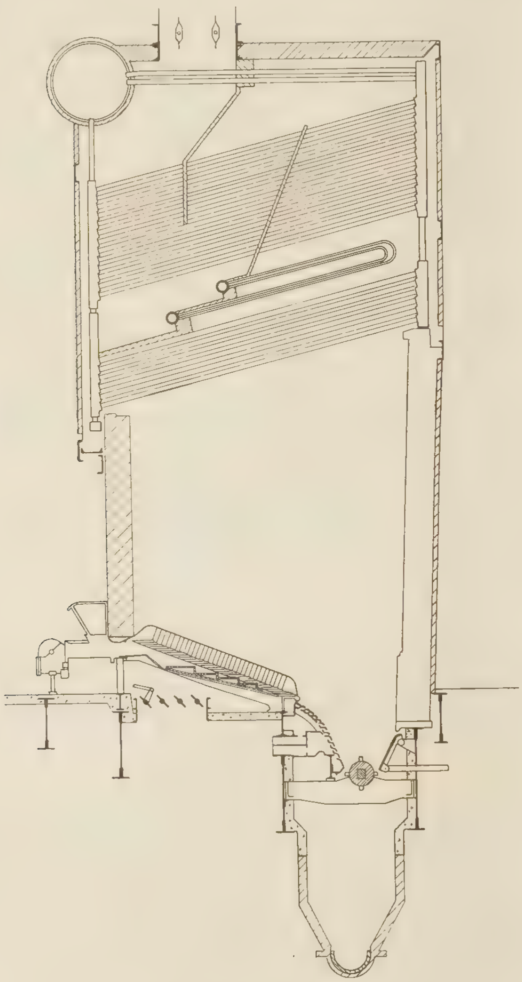


Fig. 1 Combustion Engineering Company's Frederick Stoker, Units Nos. 1 and 3

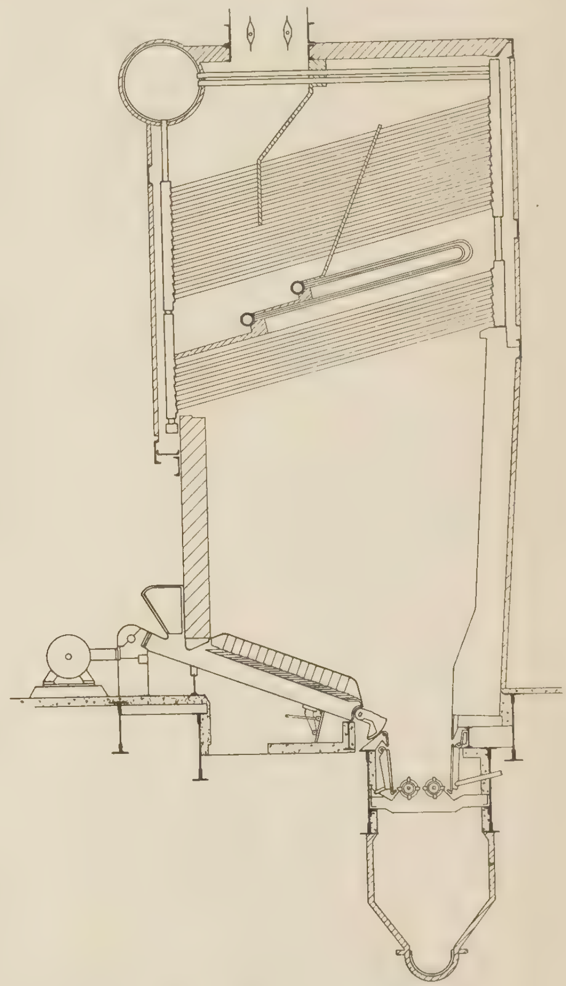


Fig. 2 Westinghouse Stoker Units Nos. 1 and 2

turbine, to take care of the increasing load demand, also to reduce the cost per kilowatt of capacity of the ultimate station.

capacity to meet the guaranteed coal-burning rates has never been tested.

Fig. 1 shows a cross-section of the Combustion stoker, and Fig. 2 shows a cross-section of the Westinghouse stoker unit as originally installed. During the first few years of their operation some changes were made from the construction shown on the drawings. The Westinghouse stoker was operated with the lower agitator grates in a stationary position, and the agitator operating mechanism removed. On the Combustion stokers the single grinder roll was rearranged to turn toward the lower grate and the retort bottoms were rearranged to use a shallower type of secondary ram which produced less disturbance and seemed to reduce clinkering troubles.

The stoker specifications issued for unit No. 4 called for a 14-retort stoker with a length not to exceed 20 ft 6 in. and capable of burning 32,000 lb of coal per hr continuously. In other words the specification called for a continuous coal-burning rate of not less than 63 lb per sq ft per hr. It should be noted in connection with the coal quantities just mentioned that at the time of unit No. 4 design work, neither the company's nor the manufacturer's engineers appreciated the existence of a rather sharp falling off in stoker efficiency at these high outputs. Hence the required coal per hour in actual operation was even higher than that specified to obtain the desired output.

The No. 4 stokers were to operate with preheated air at a tem-

perature of 300 to 450 F. Only one of the four bidders had built a stoker of the maximum length allowed. Two of them offered propositions covering stokers of the maximum length permitted. The two others did not take advantage of the full length, but offered propositions on shorter stokers, which were, however, longer than any that these two manufacturers had previously built. As a result of these negotiations, Westinghouse stokers were purchased, 39 tuyères long, having a projected length of 17 ft 4 in. and a projected grate and pit area of 427 sq ft. To burn a total of 32,000 lb of coal per hr on each stoker required a burning rate of 75 lb per sq ft per hr.

The first No. 4 stoker was initially operated in September, 1926. As shown in Fig. 4 it was designed to underfeed practically its entire length. The windbox was divided into four compartments so that different air pressures could be carried under sections of the stoker from head to foot, with an additional zone for the agitator grate. Severe burning of the tuyères occurred immediately above the plates dividing the windbox along the length of the stoker, and to overcome this the division plates were lowered to give transfer area from section to section immediately beneath the tuyères.

Numerous changes were made in the design of the retort bottom. The original bottom, as indicated in Fig. 4, had three secondary rams, the lower one acting at a different angle to the tuyère row, from the others. After several days of running, a heavy clinker formation would develop at the head end due to the lack of upward motion of the secondary rams. High ratings could not be maintained because of excessive blowing of the fuel bed and lack of burning on the clinker-blanketed upper tuyères.

The next major change made was to use a straight-line retort bottom, in which the three secondary rams acted in line along a retort bottom inclined at an angle to the tuyère row. This retort

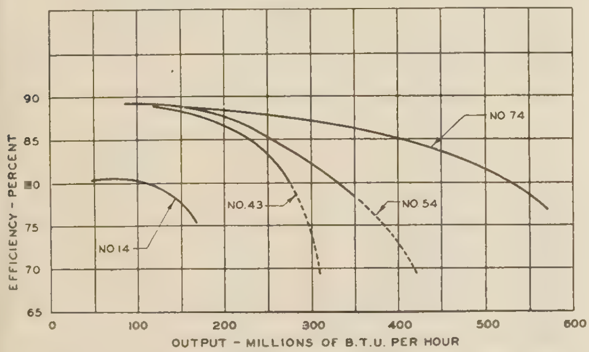


Fig. 3 Curves Showing Overall Boiler Efficiencies

produced better overall results but made the fuel bed heavy and inactive at the head in spite of many minor adjustments. Clinker on the tuyère rows, while not giving trouble at low ratings, still interfered with the obtaining of high coal-burning rates. With the thought that a greater air-entry area into the upper section of the stoker would increase the combustion rate at this point, the next step was to install longer tuyères at the head end which had double the air-passage area of the standard tuyère. This change seemed to have no appreciable beneficial effect on the obtaining of high ratings. A third major change consisted in raising the retort bottom along its entire length to shallow the retort and obtain greater agitation and looseness of the fuel bed. Again this third attempt failed to eliminate clinker on the tuyère row at the upper end. In order to get still more upward motion of coal out of the retorts at the upper end, the fourth major change consisted of making the upper secondary move upward toward the tuyères as well as down the retort and lift coal on its top surface into the fuel bed. This change eliminated, very effectively, clinker immediately above the special upper secondary ram but in the section of fuel bed immediately following, tuyère clinker was experienced.

The final change made was to install telescoping rams as shown in the lower view of Fig. 4, which combined the effective motion down the retort of the straight-line design, and a uniform upward motion of green fuel toward the tuyères. On test, this design was capable of maintaining a uniform fuel bed over its entire

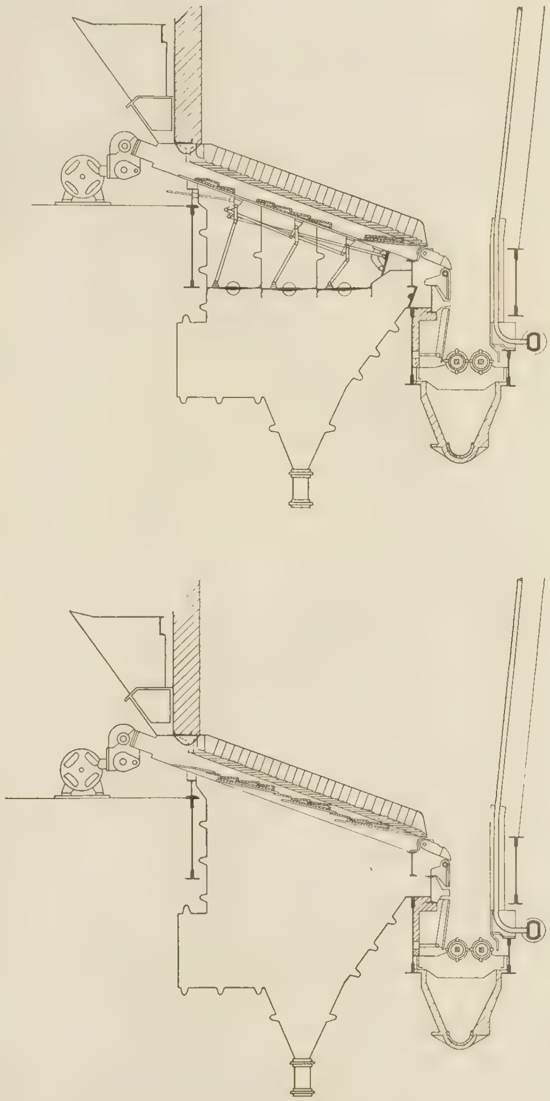


Fig. 4 Westinghouse Stoker Unit No. 4. Upper View, Original Installation; Lower View, Later Underfeed Arrangement

length at coal-burning rates up to approximately 53 lb per sq ft per hr for 24-hr periods. Rates as high as 60 to 65 lb per sq ft per hr could be maintained for 4-hr periods. At this burning rate, however, the fuel bed tended to become sensitive and was likely to blow off in any section. A point had been reached where there was an apparent limitation on continuous capacity, after every reasonable possibility had been investigated in the development of the underfeeding retort.

While this development work was going on for unit No. 4, plans were in progress for further addition to the generating capacity of the station, calling for four additional boilers and stokers to serve a 110,000-kw turbine known as unit No. 5. The development of the thin, water-cooled furnace wall made it possible to provide one extra retort in the width of each stoker within the same overall limits of furnace dimension. A return was made to

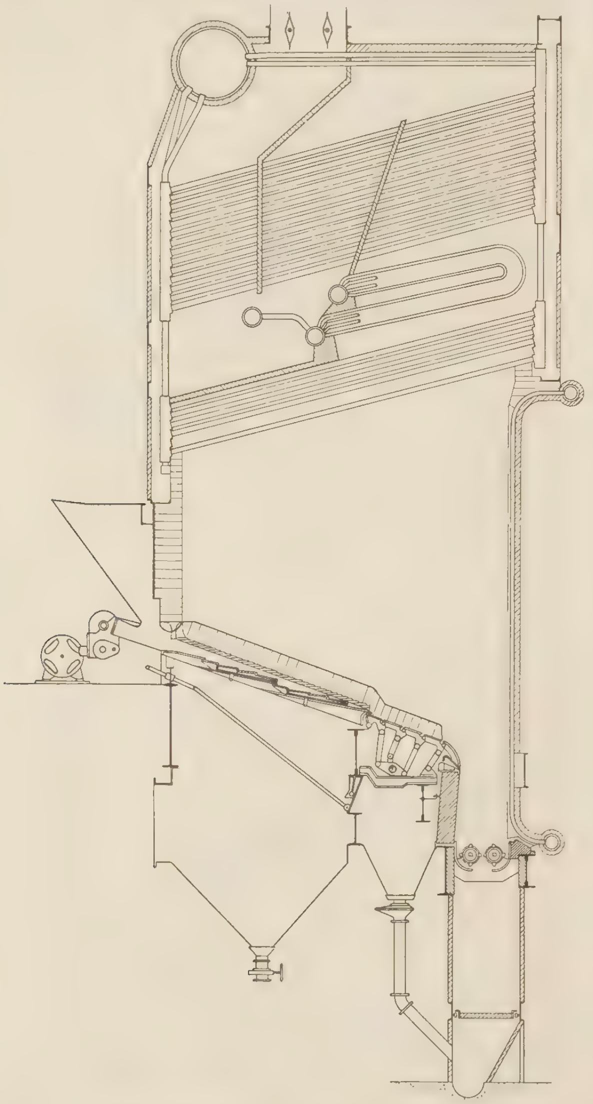


Fig. 5 Westinghouse Link-Grate Stoker Unit No. 5

cold-air operation, because economizers offered an effective substitute for air heaters in attaining economy and because space limitations practically prohibited the installation of the necessary duct work for preheated air on two adjacent units. It has been found, too, that the common-duct, preheated-air system, which had been necessary due to lack of space for a unit system, severely handicapped stoker- and boiler-maintenance work because of high temperatures resulting from leaky dampers.

For No. 5 unit, 15-retort Westinghouse stokers were purchased, having a projected length from inside of front furnace wall to rear of ashpit of 19 ft $8^3/_4$ in. and a projected stoker and ashpit area of 524 sq ft. The proposal was based on a stoker designed along the lines of No. 4 unit stokers, but of 45-tuyères length instead of 39. The guarantees were somewhat more conservative than those for unit No. 4, based on capacity per sq ft, and were as follows:

Continuous, 24-hr	58 lb per sq ft per hr
Four hours	65 lb per sq ft per hr
Two hours	73 lb per sq ft per hr

Before development of the drawings for this installation had proceeded very far, the Westinghouse Company had developed the idea of their "link-grate" stoker. They proposed this design for installation on this contract, making the statement that they believed this new development had possibilities greater than the conventional underfeed stoker. It was agreed that the installation should proceed on this basis. A sealed-ashpit design was incorporated in the No. 5 unit installation and subsequent installations, in order to eliminate the downward flow of air and

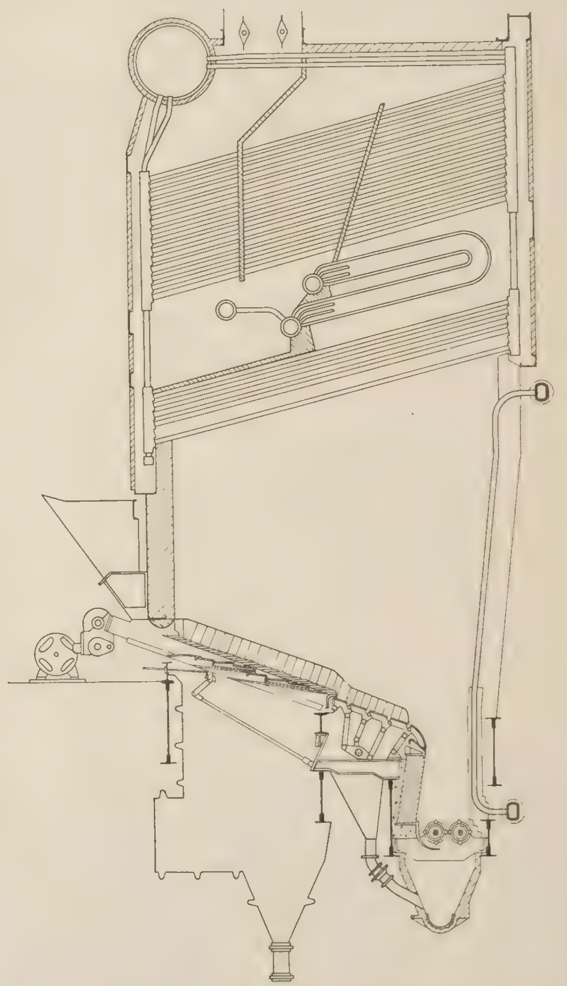


Fig. 6 Westinghouse Link-Grate Stoker Unit No. 4

gas into the ashpit which had often been experienced on the unit No. 4 stokers and had resulted in high maintenance costs for the ashpit and lower stoker parts.

The link-grate stoker, of which unit No. 5 at Hudson Avenue was the first installation, has been described a number of times

in the technical press.[4] Fig. 5 is a drawing of this stoker. Briefly the link-grate section consists of a six-foot-long overfeed section made up longitudinally of five bar elements which are linked together by a driving mechanism which gives the bars an undulating or wave-like motion which breaks down and distributes the fuel as it is received from the underfeed section and propels it toward the ashpit.

This installation was successful from the first, and practically no development work and operating experience were necessary in order to meet and surpass the capacity guarantees. Results of efficiency tests on No. 54 boiler and stoker are shown in Fig. 3. Data up to coal-burning rates of 62 lb per sq ft per hr (350×10^6 Btu per hr output) are for 24-hr tests, while the tests at burning rates of 76 and 89 lb per sq ft per hr are for durations of 3 hr and 2 hr, respectively.

Within a short time of the operation of unit No. 5, it was necessary to start engineering-design work on the next unit, No. 6. Because of the very satisfactory performance of the boilers and stokers for unit No. 5, and the need for speed in installation, unit No. 6 was made essentially a duplicate of unit No. 5 in these equipments. Unit No. 6 went into operation in 1930 with the same highly satisfactory results obtained on No. 5. In the entire station experience, these two rows of stokers have been outstanding for developing rated capacities without a long period of experimental work.

Subsequent to the successful operation of unit No. 5 link-grate stokers, the Westinghouse Company decided to install a link-grate section for the unit No. 4 stokers as a means of approaching their capacity guarantees. Before doing this work, the Westinghouse Company submitted revised capacity guarantees for the unit No. 4 stokers, which made them consistent in "performance per square foot," with those submitted for unit No. 5. These revised guarantees, although somewhat of a reduction, were accepted and the work proceeded and was completed in 1930. The revised capacity guarantees were easily met. Provision was also made at this time for sealing the ashpit and introducing air under pressures beneath the clinker-grinder rolls, insuring a definite upward flow of air through the clinker pit. Fig. 6 is a drawing of the link-grate stoker unit No. 4.

Specifications were issued in 1930 calling for stokers for units Nos. 7 and 8 to complete the station. Since two 160,000-kw turbines had been selected, it was necessary to obtain steam-generating capacity to supply their requirements. Originally it was thought that a boiler-house extension with two boilers, in addition to the eight then contemplated within the existing house, might be necessary for this purpose. Station-layout drawings were sent out with the specification indicating the available floor area and column arrangement in the building and the stoker space limitations. In defining the capacity requirements, it was indicated that four stoker units when operated together should have a combined instantaneous output rate, in steam, which at no time during a cycle of operation of five hours' duration per night for six consecutive nights should fall below a rate equivalent to 2,080,000,000 Btu per hr. Expressed as an average, this corresponds to a steam output of 520,000,000 Btu per hr per stoker unit. (455,000 lb of steam per hr.) This output was sufficient to supply the required steam from eight boilers inside the existing building. Stoker width was limited to 15 retorts by existing building columns carrying the coal bunkers.

Very serious consideration was given at this time to the use of double-ended stokers, because of the advantages in control of a shorter fuel bed. The problems of providing coal feed to an additional aisle, in particular the space requirements of equipment which would have been required to feed reliably from the existing bunkers, could not be solved by any reasonable layout, so that the double-end design was abandoned reluctantly and the specification was issued for single-ended stokers. Proposals were received as given in Table 2.

TABLE 2

	Stoker area, sq ft	Combustion rate, lb per sq ft per hr: 24 hr	5 hr	2 hr
American Engineering Co.	694	65.5	73	82
Combustion Engineering Co.	630	60	64.3	75
Westinghouse Co.	578	57.8	69.5	73.7

The Westinghouse Company also offered a stoker with an area of 625 sq ft, but with the same guaranteed total heat output per unit as for the 578-sq ft stoker; that is, the unit combustion rates were correspondingly reduced. While the Brooklyn Edison Company's experience with units Nos. 5 and 6 had indicated these Westinghouse guarantees to be conservative, there was still considerable margin between the total maximum output guaranteed and the desired output from the eight units. The Combustion Company's guarantee was also not high enough to obtain the desired steam output from the eight stokers. American Engineering stokers were therefore purchased on the basis of their guarantee to perform in accordance with the preceding conditions, which met the specification and station-capacity requirements. This guarantee was the only one which offered to produce the required steam without going outside the limits of the existing building.

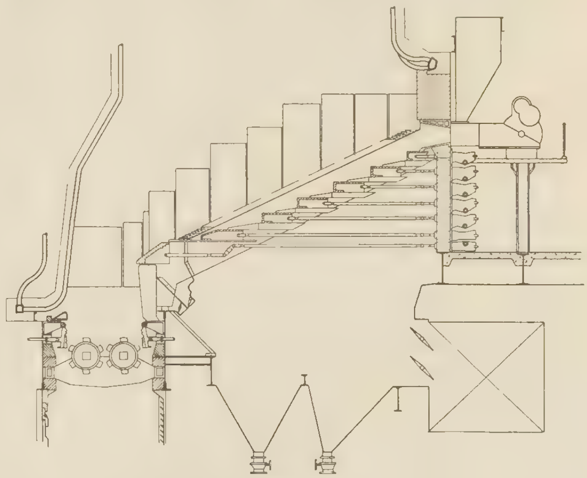


Fig. 7 Taylor Stoker Unit No. 7, Original Installation

The stokers installed were 69 tuyères long, an extension of a design previously installed at the Delray Power House No. 3 of the Detroit Edison Company which were 57 tuyères long. The retort contained six horizontally acting secondary pushers, in addition to a reciprocating extension-grate section at the lower end. Each pusher and extension grate had provision for individual adjustment of stroke external to the stoker while the stoker is in operation. Five pushers were originally of the square-nosed type, 8 in. high. The arrangement of the stoker originally installed is shown in Fig. 7.

Early operation disclosed lack of ignition at the head and a tendency for the fuel to blow off the grates as coal-burning rates of 45 to 50 lb per sq ft per hr were approached. The first move was to restrict the air supply to the front-wall air boxes and also to restrict the air to the upper tuyères at the head end of the stoker by installing baffles underneath the tuyères. Constant experiment was carried on to determine the best combination of

[4] "The Westinghouse Link Grate Stoker," *Blast Furnace and Steel Plant*, Dec., 1929.
"Underfeed Stoker Has Overfeed Rear Section," *Power Plant Engineering*, Nov. 15, 1929.

TABLE 3

Unit No.	1	3	4		5	7
Stoker No.	14	34	43		54	74
Manufacturer	Westinghouse	Combustion (Frederick)	Westinghouse		Westinghouse	American Engr. (Taylor)
Year installed	1924	1924	1926	1929	1928	1932
Width, retorts	14	14	14	14	15	15
Projected area, including ashpit, sq ft.	355	380	427	427	524	694
Projected length, including ashpit	14′5″	15′6″	17′4″	17′4″	19′6″	26′7″
Projected length, underfeed section	8′10″	9′8″	13′3″	9′4″	11′2″	18′6″
Projected length, overfeed section	1′7″	1′4″	1′7″	5′0″	5′0″	2′6″
Projected width, clinker pit	4′0″	4′6″	2′6″	3′0″	3′4″	5′7″
Boiler surface, sq ft	19,650	19,650	22,920		23,760	24,450
Economizer surface, sq ft	0	0	0		14,960	22,400
Air-heater surface, sq ft	0	0	43,290		0	0
Furnace vol., cu ft	7500	7500	7750		8500	14,000
Furnace volume per sq ft grate area	21.1	19.8	18.0		16.2	20.2
Type of furnace wall	Refractory	Refractory	Spaced water tube		Bailey block water wall	Fin tube water wall
Air temperature	Cold	Cold	300–400 F		Cold	Cold

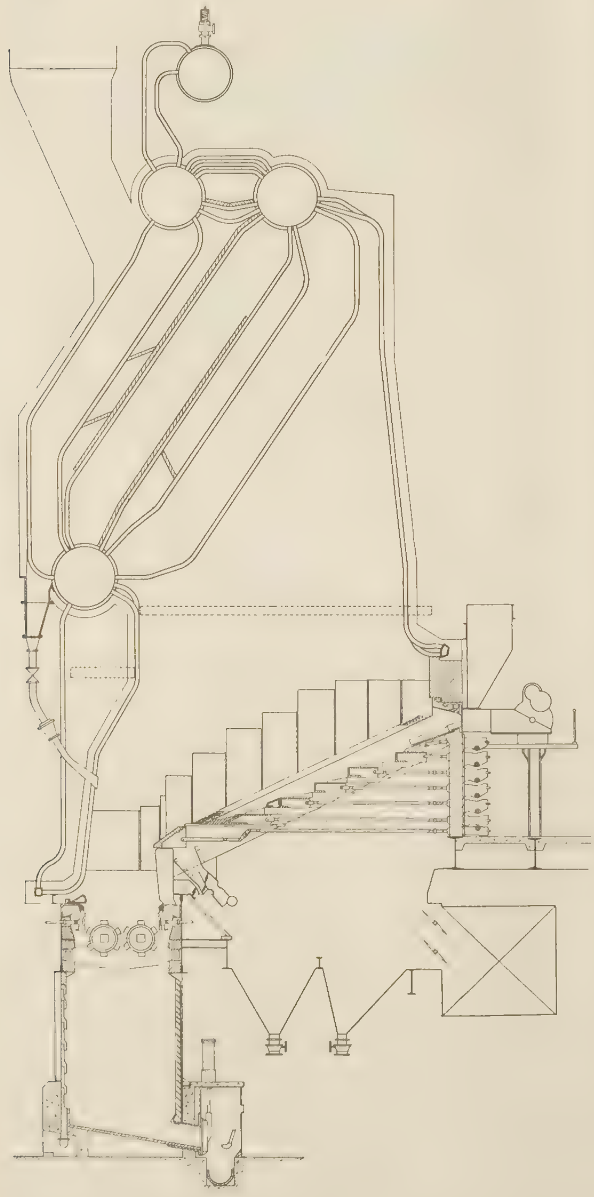


FIG. 8 TAYLOR STOKER UNIT NO. 7, REVISED ARRANGEMENT

secondary-ram strokes. Also the upper secondary ram was removed and replaced by an inclined dead plate. This effectively deepened the retort at this location, but the increased depth was below the tuyère line so that the fuel-bed thickness above the tuyère line was not increased. Then the ram-box caps, which originally had an extremely flat slope from the ram, were replaced by others, the roof slope of which could be adjusted to give an upward flare of as much as $7^1/_2$ in. from the ram out to the furnace and thus give greater depth of coal over the tuyères. With these two latter changes, some difficulty was experienced with packing of coal on the bottom of the retort at this location, which effectively shallowed the retort and also produced a disturbance to the underfeeding action. The upper dead plate was replaced experimentally with an inclined flat plate capable of reciprocating motion, with some improvement.

Other experimental changes were made on the other secondary pushers, by pulling them toward the front of the stoker, thus effectively deepening the retort; and also on other occasions by adding sections having inclined faces to the pusher noses, which effectively shallowed the retort. At the end of about a year's work, the various possibilities had been quite thoroughly investigated and the retort profile determined which gave the best results. This comprised an inclined sliding plate for the No. 1 secondary ram, which was later modified to give the retort a rounded bottom in order to reduce friction of the coal in the retort. The ram-box caps were set at a height giving a rise of about 6 in. Pushers Nos. 2, 3, and 4 were of the square-nose type, while Nos. 5 and 6 had inclined faces, with slopes approaching that of the retort. No. 6 pusher was finally installed with an inclined stepped face. With this stoker, fairly reliable operation at coal-burning rates of about 60 lb per sq ft per hr for periods of 4 to 5 hr could be obtained, with somewhat longer runs and higher ratings sometimes attainable. The experimental work described was conducted chiefly on one stoker, and during this time the operation of the stokers was entirely reliable and without excessive maintenance, the only limitation being on the maximum capacity as described.

Since the American Engineering Company had done considerable work with zoned-air control on other installations,[6] they then stated their desire to make the application to one of these stokers as their next step toward meeting the capacity guarantees. This equipment was designed and installed first on No. 74 stoker. Each row of tuyères, including the two rows of half-tuyères at the side, was divided into four equal zones and a control damper and metering venturi box and gage were provided for each zone, making 64 zones in all. The extension-grate section was divided into five zones across the width of the stoker with control damper and gage for each. The air-control apparatus arrangement under each tuyère row is illustrated in Fig. 9.

After a short period of experimental operation, this stoker

[6] "Zone Air Control for Stokers Made Automatic," F. J. Chatel, *Power*, Jan. 26, 1932.

"Zoned Air Control for Underfeed Stokers Increases Boiler Capacity," Griswold and Brown, *Power*, June 23, 1931.

"Stoker Developments at the Detroit Edison Company's Delray Power House No. 3," P. W. Thompson and F. J. Chatel, A.S.M.E. Trans., 1933, paper FSP-55-11.

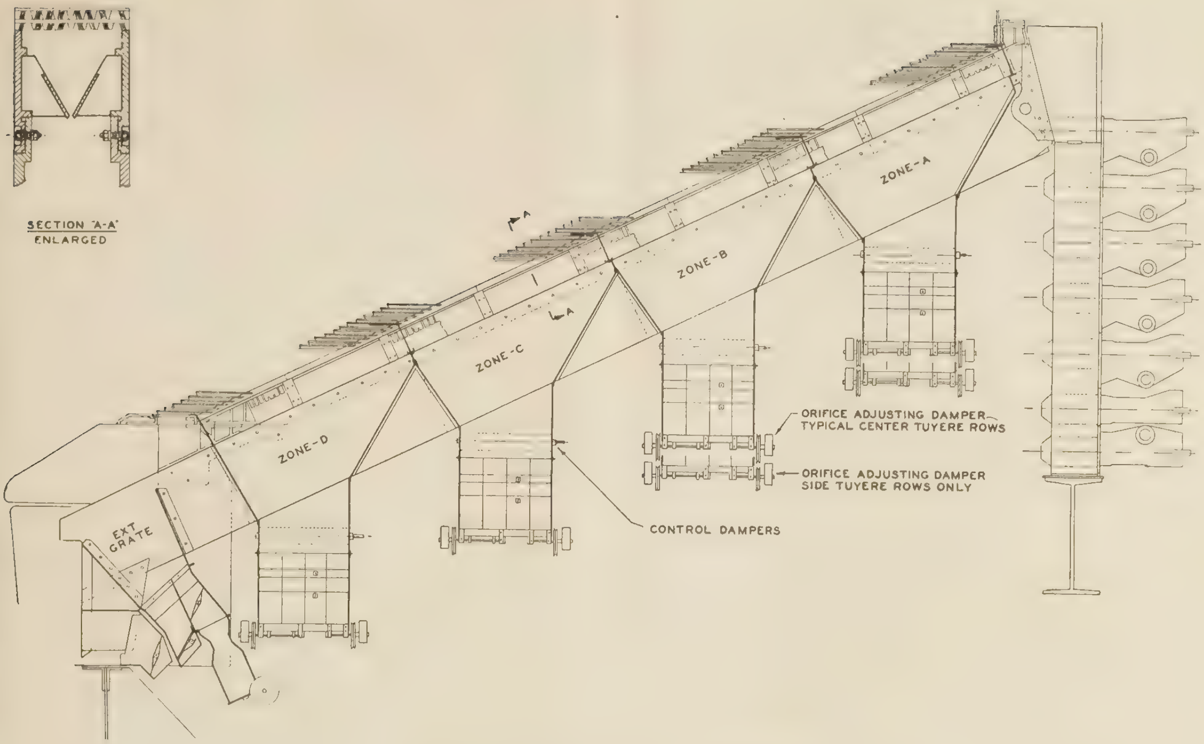


FIG. 9 STOKER AIR-CONTROL EQUIPMENT

proved itself capable of meeting the capacity guarantees and of exceeding them by a substantial margin. During the final tests on this stoker, for which water and coal were weighed, it was operated for a period of 48 consecutive hours at an average coal-burning rate of 75 lb per sq ft per hr at an average efficiency of steam-generating equipment of 77 per cent. This was at an output of approximately 500,000 lb of steam per hr.

While this point has not been mentioned in the descriptions of the individual stokers, there has been complete adoption at the Hudson Avenue Station of the so-called "thin tuyère." Thus the unit No. 4 Westinghouse stoker with link grate, having a rated underfeed section of 27 tuyères, now has actually 48 tuyères, and the newest Taylor stokers, originally 69-tuyère stokers, now actually have 100 tuyères. This type of tuyère was, in these cases, adopted by the manufacturers, and the use continued by the station operators. While they do not show any marked improvement in the manipulation of the stoker, they lessen clinkering difficulties and burning troubles, and lower maintenance costs.

DISCUSSION OF RESULTS

In considering the stoker installations, the history of which is presented here, it has been pointed out that capacity requirements made necessary the use of the most advanced developments which the stoker art afforded, both as to length of stokers and in capacity per square foot. The following points seem to the authors to warrant mentioning in a discussion of the results of these installations:

(1) As will be seen from Table 4, the general type of coal in use at Hudson Avenue has been fairly constant in character. A heating value of 14,000 Btu per lb, as fired, moisture content of 4 per cent, volatile matter of 17 to 19 per cent, and ash of 7 to 9 per cent would serve to represent this coal. Comparisons of coal-burning rates per square foot are based on coal as fired.

TABLE 4 COMPARISON OF REPRESENTATIVE COALS—STOKER TESTS

Stoker No.	14	34	43	54	74
Btu as fired	13,650	13,800	14,000	13,650	14,000
Btu dry	14,200	14,400	14,500	14,300	14,500
Moisture, per cent	4.0	4.1	3.3	4.6	3.3
Proximate analysis, dry basis					
Volatile, per cent	18.0	19.0	18.2	19.4	17.8
Fixed carbon, per cent	73.3	73.0	74.5	72.4	74.7
Ash, per cent	8.7	8.0	7.3	8.2	7.5
Ultimate analysis					
Carbon, per cent	81.0	80.8	82.3	80.7	82.1
Hydrogen, per cent	4.3	4.3	4.2	4.6	4.4
Oxygen, per cent	3.4	4.0	3.9	3.9	3.6
Nitrogen, per cent	1.3	1.3	1.9	1.3	1.3
Sulphur, per cent	1.3	1.6	0.9	1.3	1.1
Ash, per cent	8.7	8.0	7.3	8.2	7.5

While these values might have been expressed on a dry-coal basis, no standard practice in this respect seems to have been adopted, and there would still remain the variable of heating value when comparing with other installations. The importance of the heating value in comparing capacities has been pointed out in the paper by Messrs. Foresman and Mosshart of the Westinghouse Company, on "Stokers and Furnaces for New England Fuels,"[6] presented before the Boston Section of the A.S.M.E., May 15, 1929.

(2) There is some variation in the furnace volume per square foot of stoker area, which will be noted by reference to Table 3. There are also differences in the amount of "cold"-water-cooled surface exposed in the furnace. The most radical difference from the preceding units is presented by units Nos. 7 and 8, with almost completely water-cooled furnace, and an entirely different shape of furnace and disposition of furnace height with respect to the stoker.

(3) From a review of Fig. 10 it will be noted that the difference in steam-generating efficiency between the 1924 installation

[6] A.S.M.E. Trans., 1931, paper FSP-53-1.

and those made since 1926 is about 8 per cent. Of this difference, 7 per cent increase is accomplished by the reduction of dry-gas loss. This reduction is due chiefly to the installation of heat-recovery equipment beyond the boiler surface. A portion of it, representing about one-half of one per cent in the heat balance, was accomplished by a reduction of excess air. The use of water-cooled furnace walls made practical the use of higher furnace temperatures of combustion, and the improved methods of fuel and air control, particularly in the extension-grate zone, facilitated the accomplishment of the reduction of excess air. The introduction of the sealed ashpit probably assisted in the reduction of excess air at low ratings.

The combustible in refuse loss has been reduced from about 1.5 or 1.7 per cent in the heat balance to a loss of generally less

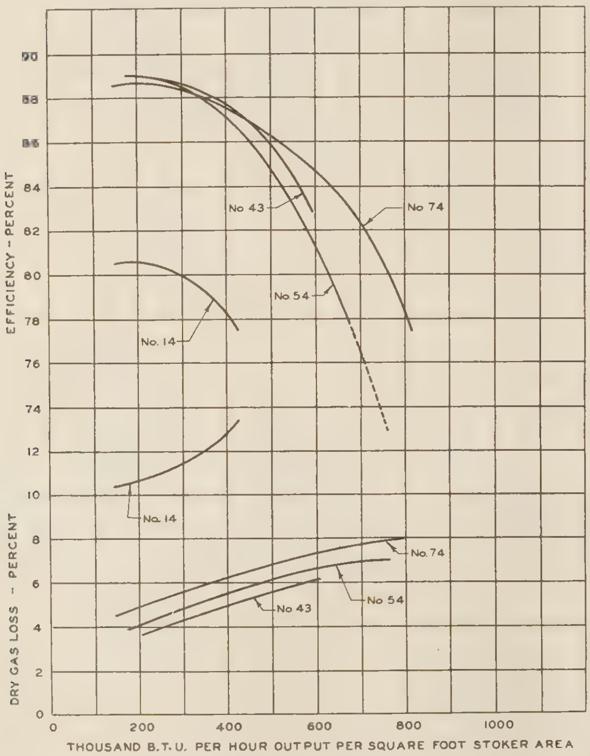


Fig. 10 Diagram Showing Steam-Generating Efficiencies and Dry-Gas Loss for Various Stokers

than 0.5 per cent. Credit for this is due mainly to the improvements in the extension-grate section and to the sealed ashpit, which latter permits more complete burning out of combustible in the ash particularly at higher ratings when "popcorning" of fuel into the more quiet zone of the pit takes place on all stokers.

(4) As operating capacities were increased to burning rates of 50 lb per sq ft per hr and above, the standard boiler test showed increasingly large unaccounted-for losses in the heat balance. Consideration of this question indicated two probable identities for these unmeasured losses; first, the fly cinder and coke carried off the fuel bed with the gas, and second, unburned gases or products of partial combustion, such as hydrogen, hydrocarbons, and carbon monoxide. Carbon monoxide is mentioned because of indications that the usual Orsat analysis apparatus did not give as high an indication of this gas as was shown to be warranted by other check methods. The Brooklyn Edison Company has given considerable attention to the development of cinder-sampling methods for determining the cinder losses and to laboratory methods of gas analysis from samples taken in the field for the more complete determination of losses due to unburned or partially burned combustible gases. This investigational work was reviewed by W. F. Davidson of this company in a paper entitled "Reduction of Unaccounted-For Losses in Boiler Tests," presented at the Chicago Meeting of the A.S.M.E. in 1931. Appli-

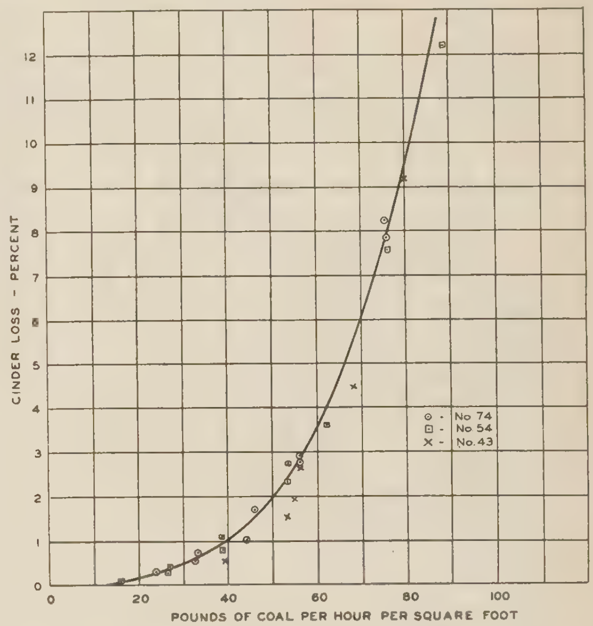


Fig. 11 Cinder Loss Plotted for Three Stoker Units

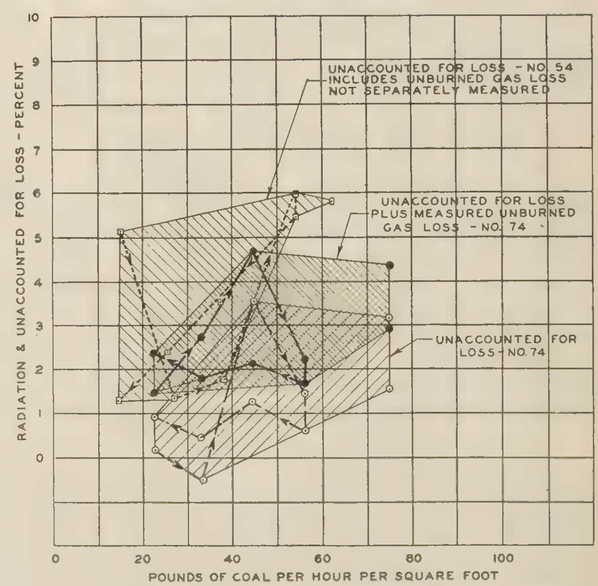


Fig. 12 Diagram Showing Unaccounted-For Losses

cation of these methods of test and analysis has resulted in the obtaining of extremely consistent results regarding cinder-loss values, and a gratifying reduction in the residual values of "radiation and unaccounted-for losses" obtained on test. A discussion of the methods and apparatus used on the 1934 tests is given in a companion paper by Messrs. Hardie and Cooper of the Brooklyn Edison Company research bureau, entitled "The Test Perform-

ance of Hudson Avenue's Most Recent Steam-Generating Units."[3]

(5) The increase in cinder loss at the higher ratings which has been referred to is a reflection of the growing instability of the fuel bed as burning rates are increased. This condition, resulting from inequalities in the thickness and porosity of the fuel bed, has also been discussed by Messrs. Foresman and Mosshart with reference to the duration of time for which any rating may be carried.

The cinder losses for three of the stoker units most recently tested, namely, Nos. 43, 54, and 74, are plotted in Fig. 11. These losses were calculated from the gas flow after determining the cinder loading of the gas in the uptake by the sampling method as described in the paper by Hardie and Cooper. In this connection, it should be pointed out that the cinder loss for No. 74 stoker was measured under conditions of operation which provided for the return to the ashpit of that portion of the cinder which was trapped in the hoppers of the boiler at the bottom of the third boiler pass. These hoppers and the return piping system are indicated in Fig. 8. This method of operation assisted in raising the efficiency of No. 74 stoker on test by reclaiming heat which otherwise would have appeared in the cinder loss. The low value of combustible in refuse loss indicates that the cinder returned to the pit was quite completely burned.

TABLE 5 OPERATING DATA FOR HUDSON AVENUE STATION, 1925–1933

(Based on service hours per year)

Year / Row	1925	1926	1927	1928	1929	1930	1931	1932	1933
1—Average steaming rate—1000 lb per hr per boiler									
11–14			75.3	64.5	56.0	63.0	52.3	.....	.....
21–24	69.3	76.7	78.1	64.4	58.4	64.1	54.9	.....	.....
31–34			72.9	61.9	53.9	58.0	46.6	.....	.....
41–44	....	123.7	142.8	144.8	138.1	132.0	126.2	103.2	.....
51–54	....	.....	.....	166.8	181.8	180.7	162.4	134.0	131.7
61–64	....	.....	.....	.....	.....	160.8	165.8	135.3	127.3
71–74	....	.....	.....	.....	.....	.....	.....	179.2	197.0
81–84	....	.....	.....	.....	.....	.....	.....	172.6	186.9
2—Average coal-burning rate, lb coal per sq ft per hr									
11–14			21.0	17.9	15.7	17.3	14.7	.....	.....
21–24	20.3	20.9	21.8	18.6	16.7	17.9	15.7	.....	.....
31–34			19.4	16.6	14.5	15.5	12.9	.....	.....
41–44	....	27.8	31.9	33.0	31.8	30.7	27.1	22.4	.....
51–54	....	.....	.....	32.1	34.8	33.4	29.4	24.5	24.0
61–64	....	.....	.....	.....	.....	29.7	31.1	25.1	24.0
71–74	....	.....	.....	.....	.....	.....	.....	24.9	27.2
81–84	....	.....	.....	.....	.....	.....	.....	23.3	25.2
3—Average steam-generating efficiency—per cent									
11–14			78.0	77.5	75.5	75.7	74.9	.....	.....
21–24	72.7	79.0	80.2	77.1	76.7	77.2	76.0	.....	.....
31–34			78.9	78.0	76.0	75.4	72.9	.....	.....
41–44	....	79.9	81.1	79.8	76.1	75.5	82.3	83.3	.....
51–54	....	.....	.....	83.4	82.7	84.2	86.4	86.3	85.9
61–64	....	.....	.....	.....	.....	85.2	85.5	86.5	85.3
71–74	....	.....	.....	.....	.....	.....	.....	85.3	85.0
81–84	....	.....	.....	.....	.....	.....	.....	87.5	87.3
4—Stoker-maintenance cost—dollars per net ton									
11–14	0.141	0.143	0.128	0.121	0.108	0.174	0.108	.....	.....
21–24	0.119	0.094	0.065	0.086	0.085	0.089	0.099	.....	.....
31–34	0.138	0.170	0.173	0.174	0.232	0.124	0.132	.....	.....
41–44	....	0.086	0.054	0.144	0.210	0.203	0.090	0.173	.....
51–54	....	.....	.....	0.025	0.043	0.075	0.071	0.063	0.043
61–64	....	.....	.....	.....	.....	0.031	0.052	0.044	0.034
71–74	....	.....	.....	.....	.....	.....	.....	0.036	0.080
81–84	....	.....	.....	.....	.....	.....	.....	0.034	0.068

(6) In comparing the efficiency results of stokers Nos. 54 and 74, it will be noted that while the cinder-loss points, as determined at the boiler outlet, lie close to a common curve and the dry-gas loss for No. 74 is higher than for No. 54, the efficiency for the No. 74 unit is higher at the same coal-burning rate. The reason for the difference in efficiency is of interest and lies in the greater "unaccounted-for" loss in the No. 54 test. Although the unburned-gas losses were not measured on the No. 54 test, it is believed that these largely account for the difference. The "unaccounted-for" losses, which include radiation and all test errors, are shown in Fig. 12. A comparison is also given with the sum of "unaccounted-for" and unburned-gas losses for No. 74, since the unburned-gas loss for No. 54 is included in the "unaccounted-for" classification. This comparison shows the No. 54 losses somewhat higher. All of the test points shown on this illustration are for 24-hour tests with weighed coal and water. Cinder loss and other measured losses were obtained by similar procedures in each case. The reduction in unburned-gas and unaccounted-for losses in the No. 74 test may be attributed partly to the air-control equipment and also to better furnace conditions, namely, greater furnace volume and what is undoubtedly a superior arrangement of furnace for stoker firing, namely, a long gas path from the head of the stoker to the boiler-heating surface, as contrasted with the comparatively short gas path for No. 54.

(7) It is interesting to note that for unit No. 4, which was installed as an underfeed stoker, with a projected length including ashpit of 17 ft 6 in., after a long period of experimenting and numerous changes which developed it to its best operating condition as a purely underfeed stoker before the installation of the link grate, a limitation on stable operation for long periods was reached at a burning rate of about 55 lb per sq ft per hr. This stoker operated with preheated air.

For unit No. 7, an underfeed stoker of different manufacture with a projected length of 26 ft $7^1/_2$ in. including ashpit, after a long period of development which brought it to its best operating condition as a purely underfeed stoker, without zoned-air control apparatus, a limitation on stable operation for long periods was reached at about the same value of 55 lb per sq ft per hr.

It is known that this capacity limitation does not apply to extremely short stokers, probably because of the better opportunity for operating supervision and the quicker response of the fuel bed to control measures. The exact length at which this capacity limitation becomes effective is not known from experience at Hudson Avenue; it is probably considerably shorter than the approximately 13-ft-long underfeed section of the original unit No. 4 installation.

(8) The use of the link-grate overfeed section at the lower end of an underfeed stoker had the effect of raising the capacity limitation compared with the purely underfeed stoker. With a six-foot section of link-grate construction substituted for the usual tuyère row and retort construction, the maximum, continuous, overall coal-burning rate on the combined underfeed and overfeed area of the stokers described was raised to approximately 65 lb per sq ft per hr. An explanation of this increase in coal-burning rate may be in the following: The pure underfeed section is shortened, thereby facilitating its control and raising the combustion-rate limitation on that section. As the coked fuel passes on to the link-grate section it is broken down and spread out to form a very porous fuel bed, through which a windbox pressure lower than that needed for the underfeed section will pass the required combustion air. Thus, in the event of the formation of a weak spot in the fuel bed, the potentialities for the blowing out of the local section of the fuel bed, due to a sudden conversion from windbox static pressure to velocity pressure, are reduced.

(9) The use of zoned-air control equipment brings back to the long stoker the control element formerly lost by comparison with the short stoker. The provision of metering boxes and

gages to indicate the flow conditions enables the operator to interpret the condition of the fuel bed at various points. The adjacent damper control provides the means to control the flow to correct any irregular condition indicated by the metering gages. The effectiveness of this control may be judged from the fact that during the two consecutive 24-hour test runs on No. 74 stoker at a coal-burning rate of about 75 lb per sq ft per hr, the air control alone was manipulated, the strokes of the six secondary pushers were not changed, gear-box ratio was not changed, and stoker speed was adjusted on an average of only once in two hours, by an almost negligible percentage.

(10) It is interesting to note that the apparent limitation of the plain underfeed stoker, due to lack of control of fuel and air, has been met by two manufacturers by two entirely different developments, opening up further possibilities in the efficient burning of coal for heat and power. This method of increasing capacity by the more effective use of existing floor areas and more intensive use of equipment results in a lower cost per kilowatt of installed capacity, and is particularly adapted to the peak requirement which is characteristic of electrical central-station service.

(11) A summary of the results of nine years of stoker operation, from 1925 to 1933, inclusive, giving average boiler steam-output rate, average coal-burning rate, average boiler efficiency, and average stoker-maintenance costs is given in Table 5. The relatively low average coal-burning rates result from the low station loads during the early morning hours. The completion of the link-grate installation on No. 4 unit in 1930 is reflected in the improved steam-generating efficiency and stoker maintenance figures in the years following.

(12) As to the future possibilities for higher coal-burning rates per square foot of stoker area (it being an author's prerogative to make a few predictions), the chief loss of magnitude which remains to be attacked by future development is the cinder loss. It would seem that to decrease this loss, stoker grates and coal-feeding mechanisms will have to be changed radically from their present, design to one which will produce a much higher ratio of air-admitting area to total grate area and which will distil the volatile, and coke the fuel rapidly within a very short section of the total stoker length.

In closing, the authors wish to state that in presenting this paper it is their intention to make available information on the performance and capacity abilities and limitations of long stokers when burning eastern bituminous coal; the stokers discussed representing, in the present state of the art, the most advanced developments in stoker length and coal-burning capacity.

The authors also wish to compliment the manufacturers on the persistence displayed by them in finally overcoming the many problems with which they had to cope and on the successful completion of their contracts and meeting of their guarantees.

Use of Current Meters for Precise Measurement of Flow

By FLOYD A. NAGLER[1]

In this paper the author deals with the art of flow determination by current meter, compares the accuracy of this method with that of other means of water measurement, and draws attention to a number of precautions which should be observed in order to minimize error. He compares also the characteristics of cup and screw meters, discusses meter ratings, the effects of turbulence and angularity of flow, describes the channel sections best suited to accurate gaging, and covers in some detail the technique of flow determination under varying conditions in the field.

Precision Obtainable Only With Proper Use of Reliable Meter

THE CURRENT METER is an indicator of the velocity at only one point in the cross-section of a stream; it does not measure flow directly. Flow may be obtained, however, with any reliable current meter more or less precisely depending upon the intelligence displayed in the use of this instrument in scanning the cross-section of the stream and the consideration given to the variations and disturbances in flow. Its use in measuring flow is analogous to the technique required in using the pitot tube or any other velocity-measuring instrument. Thus, perfect instruments do not insure precise measurements. The proper use of the current meter in integrating the velocities is as essential to a precise measurement of flow as the reliability of the current meter itself in indicating the correct forward component of velocity along its axis.

Types of Meters

Current meters in common use at the present time are generally classified, with respect to the type of their rotating element, as either cup or screw meters.

The rotating element of a cup meter turns about a vertical axis. This type is being used extensively by the United States Geological Survey who have adopted the improved Price meter (see Fig. 1) as the most dependable current meter for use in the measurement of the flow of American rivers.

The propellers of screw meters rotate about a horizontal axis. Meters of this type are available in many designs, the most common of which are the Fteley, Haskell, Hoff, and Ott meters. The Haskell meter (Fig. 2) has been employed in measuring the discharge of some of the larger American rivers, the new Hoff meter (Fig. 3) has been used extensively in some of the western states, while Ott meters of several different designs (Figs. 4 and 5) are occasionally used in making the more precise measurements of flow in volved in laboratory work and hydroelectric development

Meter Ratings

The characteristics of these meters as indicated by their ratings in still water are well known:

(*a*) Meters are available which with good care maintain their rating in an entirely satisfactory manner for velocities greater than one foot per second.[2]

Fig. 1 Improved Price Current Meter

(*b*) In contrast to the screw meter, the cup meter does not register properly near the water surface or the walls of the channel.[3]

(*c*) Like all instruments of precision, meters of the same type differ in their rated characteristics. They also give different results with different types of support. Hence, in rating, meters should always be supported in the manner in which they are used in the field.[4]

[1] Deceased. Dr. Nagler was graduated from Michigan State College in 1914 with the degree of B.S. In 1915 he received the degree of M.S.E. and in 1917 that of Ph.D. from the University of Michigan. From July, 1909, to September, 1910, he was electric meterman with the Commonwealth Power Co. and from October, 1914, to June, 1917, he was a graduate student in hydraulic engineering at the University of Michigan. From 1917 to 1920 Dr. Nagler was associated with Robert E. Horton, Consulting Engineer, Albany, N. Y., and in 1920 went to the State University of Iowa as assistant professor. In 1922 he became associate professor of mechanics and hydraulics and in 1928 he was appointed professor of hydraulic engineering at the State University of Iowa. Dr. Nagler held this position until his death, November 10, 1933.

Contributed by the Hydraulic Division and presented at the Annual Meeting, New York, N. Y., December 4 to 8, 1933, of The American Society of Mechanical Engineers.

[2] "The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, p. 126.

[3] "Accuracy of Stream Measurements," by E. C. Murphy, Water Supply and Irrigation Paper No. 56, 1901, U. S. Geological Survey.

"Behavior of Cup Meters Under Conditions Not Covered by Standard Ratings," by F. C. Scobey, *Jour. of Agric. Research*, May 25, 1914, pp. 77–83.

"The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, p. 126.

[4] "Accuracy of Stream Measurements," by E. C. Murphy, Water Supply and Irrigation Paper No. 56, 1901, No. 95, 1903, U. S. Geological Survey.

"Meter Ratings With Various Suspension Arrangements" and "The Rating and Use of Current Meters," by C. Rohwer, Tech Bull. No. 3. Colorado Agric. College, pp. 127 and 128.

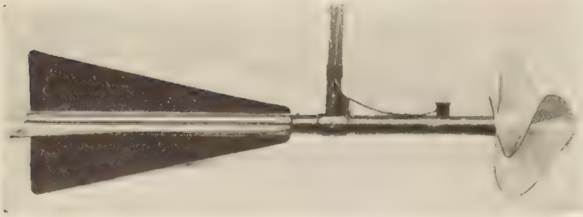


Fig. 2 Haskell Current Meter

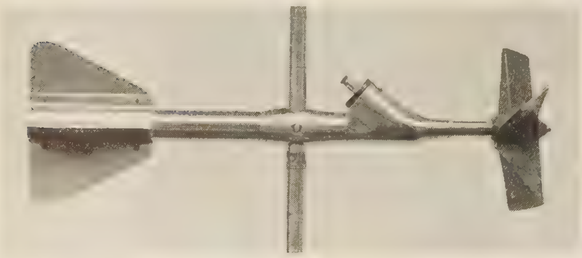


Fig. 3 Hoff Current Meter

Fig. 4 Ott Current Meter—Type VIb

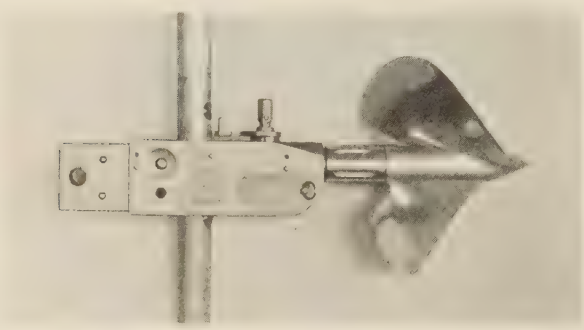


Fig. 5 Ott Current Meter—Type V

(*d*) Ratings at tangent stations have generally been considered to be more reliable than ratings made at rotary stations. However, there is generally good agreement between the results obtained at tangent and rotary stations, although a small difference in rotation of the meter has been observed at some rotary stations.[5]

Still-Water Rating Vs. Performance in Flowing Water

The streamline filaments encountered by a current meter when towed through quiet water are obviously quite different from the more or less perturbed movements of water that strike the rotating element of a meter when held stationary in a flowing stream where parallel filaments of flow seldom are seen and cross currents, vortices, and eddies are frequently encountered.

A few attempts have been made to discover the difference between still-water ratings and performance in flowing water by towing the meter with and against a steady current.[6] At ordinary velocities the still-water rating has given no different result from that obtained in mildly flowing water. However, to date, these tests have been made only in well-behaved water with only a mild current, hence the only conclusion that may safely be drawn is that still-water ratings should give satisfactory indication of meter performance when ideal conditions of flow are encountered. Towing experiments of this type in streams with higher velocity and greater turbulence are needed to check the results obtained by analytical methods.

Effect of Turbulence

When a current meter operates in a turbulent stream, the action of the water upon the propeller differs from the action of the streamline flow encountered in rating, in that

(*a*) The velocity of successive portions of the stream coming in contact with the propeller may vary rapidly in magnitude
(*b*) The distribution of the filaments of velocity over the plane of the propeller may not be uniform
(*c*) The water frequently strikes the rotating element at an oblique angle
(*d*) The obliquity of the current coming in contact with the propeller may vary rapidly in direction.

Error Due to Inertia of Rotating Element

The error in registration due to failure of the meter to respond to rapid changes in water velocity has been studied both by oscillating the meters in an upstream and downstream direction while being towed in still water and also by producing similar oscillations while measuring the velocity of flowing water. Under the influence of rapid variations in the velocity of the flowing water, experiments have indicated that all types of meters give satisfactory performance unless the velocity is exceedingly low, or unless upstream velocities are encountered. The meters with light aluminum or rubber propellers give no better performance in this respect than those with rotating elements made of brass or copper.[7] In this connection it is interesting to note that the Robinson cup anemometer over-registers in gusty winds of variable speed.[8]

Effect of Oblique Currents

The effect of oblique currents on various types of meters has been studied by towing meters in still water with the meter axis inclined at various horizontal and vertical angles, by holding the

[5] Discussion by Charles M. Allen, Proc. Engrg. Soc. of Western Pa., vol. 30, 1914–1915, pp. 401–402.

"The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, pp. 128–130.

[6] "Über die Umlaufbewegung der hydrometrischen Flügel," by Hajos, 1902.

"The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, pp. 56 and 57.

[7] "Characteristics of Cup and Screw Meters," by B. F. Groat, Trans. A.S.C.E., vol. 76, 1913, pp. 819–840 and 852–870.

"Chemi-Hydrometry and Its Application to the Precise Testing of Hydroelectric Generators," by B. F. Groat, Trans. A.S.C.E., vol. 80, 1916, pp. 1231–1271.

"Effect of Turbulence on the Registration of Current Meters," by David L. Yarnell and Floyd A. Nagler, Trans. A.S.C.E., vol. 95, 1931, pp. 780–784.

[8] "The Effect of Inertia on the Motion of an Anemometer Cup Wheel Exposed to a Wind of Variable Speed," by G. Grimminger, Bull. Amer. Meteorological Soc., June-July, 1933, pp. 161–164.

meters stationary in a steady current with the meter axis turned at various angles to the direction of flow, and by oscillating the meter laterally or vertically while towing it in still water.[9,10,11] The results of all such experiments are in fair agreement, and apparently the effect of oblique currents upon the registration of various types of meters can be determined with satisfactory precision. The following significant facts have been determined from these tests:

(*a*) Screw meters under-register the forward component of oblique lateral currents while cup meters over-register. However, at small angles some older types of screw meters have been known to over-register slightly, while some newer types have practically perfect characteristics.

(*b*) Oblique vertical currents are also under-registered by screw meters, while cup meters may slightly under- or over-register the forward component of these same currents, depending somewhat upon the type of cup meter and whether the current is upward or downward.

(*c*) The interference of the meter frame is such that the registration of the forward component of an oblique current varies slightly, depending upon whether the current approaches the meter from right or left and from above or below.

(*d*) All meters show a slight variation in the percentage of over- or under-registration of the forward component of oblique currents of a given angle depending upon its velocity.

(*e*) The Haskell and Hoff meters under-register ordinary oblique currents to a greater extent than the Price meter over-registers these same currents.

(*f*) The best characteristics are shown by the Ott meter. If the obliquity does not exceed 20 deg its effect upon the registration of the better designs is negligible.

Other Effects of Turbulence

Very few published data are available upon the effect of non-uniform velocity distribution over the plane of the propeller and rapid changes in direction and obliquity of the stream filaments. Although there are records of many flow measurements by current meter compared with other standard methods, the results cannot be considered conclusive since the technique of using the meter and the other standard method may have entirely obliterated the deviation in meter characteristics due to turbulence.

Perhaps the Iowa tests,[12] in which various meters were held at fixed points in violently turbulent streams, are most significant in that the various meters arranged themselves in exactly the same order in degree of over- and under-registration as that determined by test of these same meters in smoothly oblique flow. This fact tends to support the present practice of precise measurements in turbulent water where the amount of absolute error in measuring the forward component of velocity is determined by measuring this velocity with two meters of different under- or over-rating characteristics. The difference in registration applied to the "oblique characteristic curve" indicates the absolute error of the meter giving the better performance. Hence, this average obliquity is assumed to represent a rather obscure measure of the degree of turbulence.

Use of Current Meter

As a metering instrument, all that is expected of the ideal current meter is that it register the true forward component of velocity of only that filament of the stream encountering the propeller. Whether this instrument or any other instrument that indicates only the velocity at a single point in the cross-section of a stream can be used to obtain a precise measurement of the flow of a stream, raises a question which is entirely independent of the considerations that have thus far been given to meter characteristics. The current meter can be used to scan the irregularities in velocity across the section of a stream, but the precise measurement of flow demands that this scanning be thoroughly done and that there be no doubt as to the exact cross-section of flow.

Ideal Section

In addition to a section free from turbulence so that the meter performance will be beyond question, the ideal location for a precise current-meter measurement should (*a*) insure reliable scanning by the maintenance of steady flow, with the minimum amount of irregular variations in velocity throughout the section; (*b*) furthermore, in order to accurately measure the area of the cross-section, the metering section should be fixed and regular. It is ridiculous to expect to obtain a precise measurement of flow where the bed of the stream is rocky and irregular or soft and movable. Unfortunately, ideal sections seldom exist, and the degree of precision attained in a measurement can always be gaged by the extent to which the ideal section is realized.

Steady Flow

Water generally moves in pulsations and waves. Flow cannot be measured precisely with current meters when the pulsations are large in magnitude, or when the rate of discharge is changing rapidly. Increase in the number of meters and period of observation may reduce errors in certain cases of unsteady flow.

Expanding cross-sections must be avoided. Due to the steadying influence of contracting channels, sections located where flow is accelerating often give better measuring conditions than channels with a uniform cross-section.

Excellent metering conditions were encountered in a vertical section through the nappe of water discharging at a depth of eleven feet over the Keokuk spillway.[13] Meter readings could be duplicated to the tenth of a second at any given point. The accelerating water was absolutely steady, and lacked the pulsations in velocity commonly encountered in most measurements. Converging irrigation flumes have also been found by Rohwer to furnish the best conditions for current-meter measurements.[14]

---

[9] "On the Current Meter, Etc.," by F. P. Stearns, Trans. A.S.C.E., vol. 12, 1883, pp. 301–338.

"An Investigation of the Use and Rating of the Current Meter," by C. P. Rumpf, *Engineering News*, vol. 71, 1914, pp. 1083–1084.

"The Measurement of the Velocity of Flowing Water," by L. F. Moody, Proc. Eng. Soc. of Western Pa., vol. 30, 1914–1915, pp. 320–322.

"Behavior of Cup Meters Under Conditions Not Covered by Standard Ratings," by F. C. Scobey, *Jour. Agric. Research*, May 25, 1914, pp. 77–83.

"The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, pp. 35–51.

[10] Discussion by E. H. Brown and Floyd A. Nagler, Proc. Eng. Soc. of Western Pa., vol. 30, 1914–1915, pp. 415–424.

"Effect of Turbulence on the Registration of Current Meters," by David L. Yarnell and Floyd A. Nagler, Trans. A.S.C.E., vol. 95, 1931, pp. 784–791.

[11] "Characteristics of Cup and Screw Meters," by B. F. Groat, Trans. A.S.C.E., vol. 86, 1913, pp. 819–840 and 852–870.

"Pitot Tube Formulas, Facts and Fallacies," by B. F. Groat, Proc. Eng. Soc. of Western Pa., vol. 30, 1914–1915, pp. 351–366.

"Chemi-Hydrometry, Etc.," by B. F. Groat, Trans. A.S.C.E., vol. 80, 1916, pp. 1231–1271.

[12] "Effect of Turbulence on the Registration of Current Meters," by David L. Yarnell and Floyd A. Nagler, Trans. A.S.C.E., vol. 95, 1931, pp. 770–780.

[13] "Experiments on Discharge Over Spillways and Models, Keokuk Dam," by Floyd A. Nagler and A. Davis, Trans. A.S.C.E., vol. 94, 1930, pp. 777–844.

[14] "The Rating and Use of Current Meters," by C. Rohwer, Tech. Bull. No. 3, Colorado Agric. College, pp. 120–122.

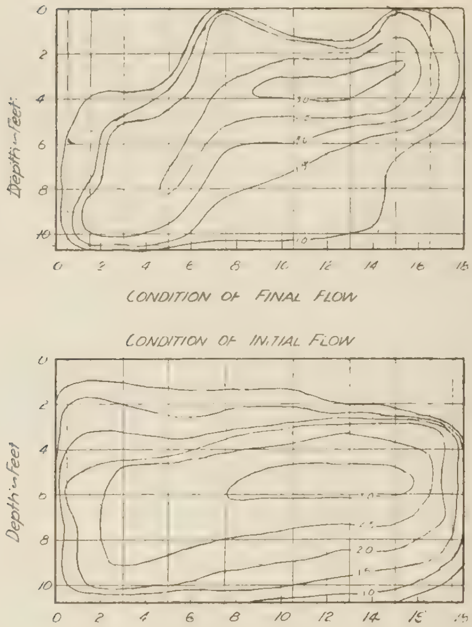


FIG. 6 VELOCITIES IN OPEN WHEEL PIT, 10 FT UPSTREAM FROM TURBINE

(Velocity contours in ft per sec; discharge = 344 cfs.)

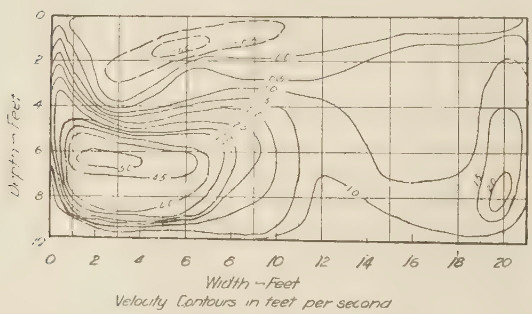


FIG. 7 VELOCITIES IN TAILRACE, 10 FT DOWNSTREAM FROM OUTLET OF ELBOW DRAFT TUBE

(Velocity contours in ft per sec; discharge = 330 cfs.)

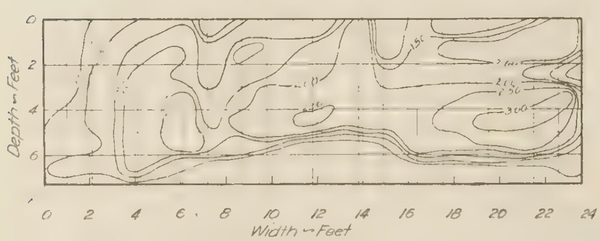


FIG. 8 DISCHARGE MEASUREMENT BY CURRENT METER AT SECTION 2 FT DOWNSTREAM FROM TRASH RACKS WITH INTERFERENCE BY SUPPORTING BEAMS AND POSTS

(Velocity contours in ft per sec; discharge = 241 cfs.)

Unstable conditions of flow must also be avoided. In an otherwise good metering section a complete turnover in velocity distribution has been experienced during a measurement. Either distribution shown in Fig. 6 could be secured, depending upon whether the condition was approached with increasing or decreasing flow. Such changes in flow distribution, if near the water turbine, are not without effect upon the turbine efficiency.

TYPE OF SECTION GENERALLY ENCOUNTERED IN WATER-POWER DEVELOPMENTS

Unfortunately, ideal current-meter sections are seldom provided in the construction of water-power plants. In this country, current meters have been used mainly to measure the discharge of low-head plants with open-flume settings where the current meter has generally offered the only means of more or less precise measurement. Draft-tube design has not yet reached the plane where flow conditions in short tailraces are at all adequate for the precise measurement of flow. The distortion of contours in Fig. 7 is only a mild indication of the actual disturbances in the tailrace.

Generally, the flow is metered upstream from the water tur-

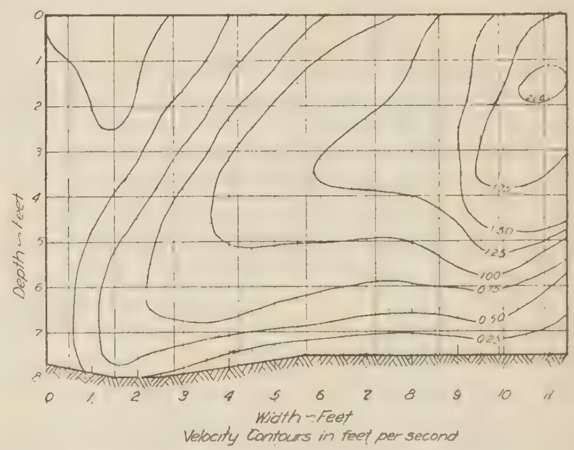


FIG. 9 DISCHARGE MEASUREMENT BY CURRENT METER IN INTAKE FLUME DOWNSTREAM FROM TRASH RACKS

(Velocity contours in ft per sec; discharge = 72.8 cfs.)

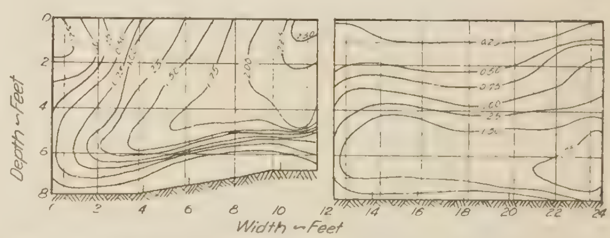


FIG. 10 DISCHARGE MEASUREMENT BY CURRENT METER AT SECTION 7 FT DOWNSTREAM FROM TRASH RACKS

(Velocity contours in ft per sec; discharge = 190.5 cfs.)

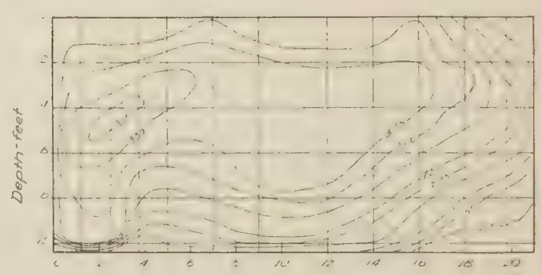


FIG. 11 DISCHARGE MEASUREMENT BY CURRENT METER AT SECTION IN APPROACH FLUME TO VACUUM SETTING

(Velocity contours in ft per sec; discharge = 597.3 cfs.)

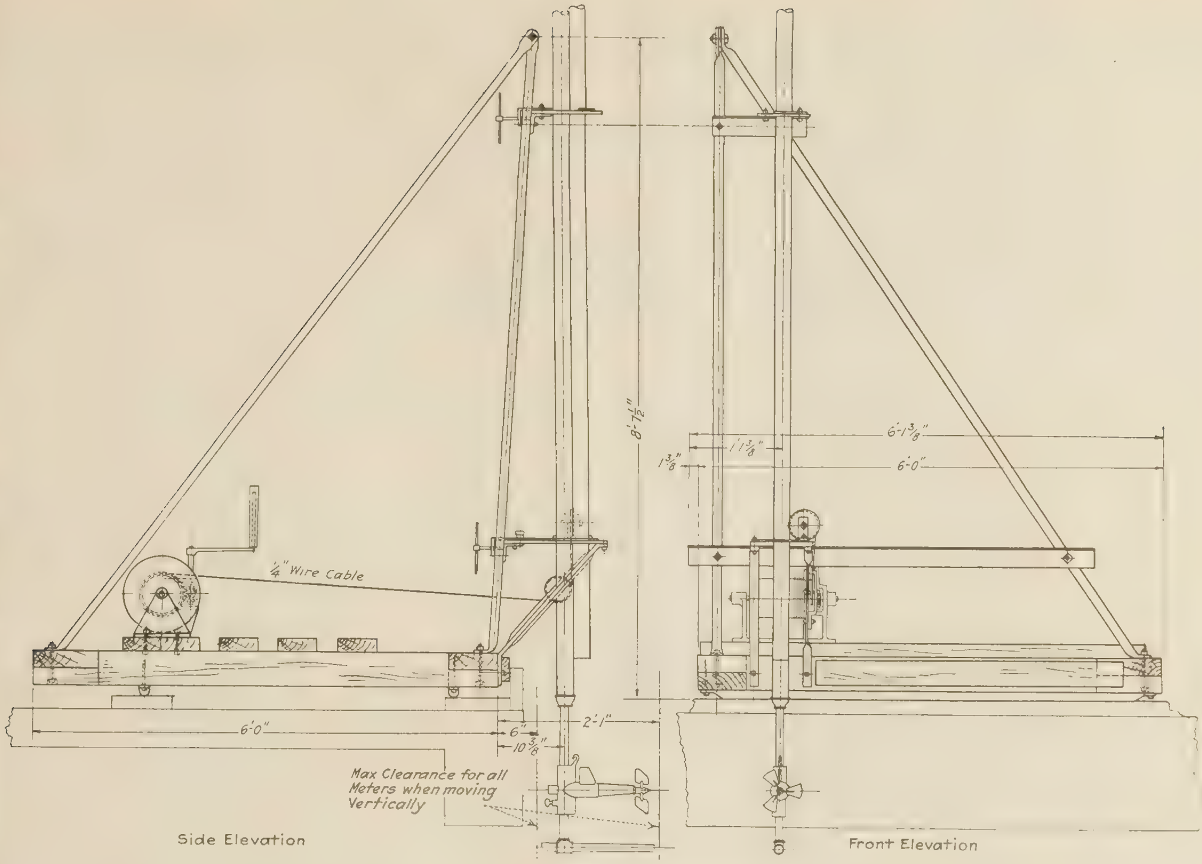


Fig. 12 Current-Meter Hoist

bine in the headrace or intake flume. The opening at the head gate or stop log groove has usually been chosen as the best available section, although dead water and turbulence caused by contractions around curtain walls, pier noses, trash racks and their supports often introduce complications into the metering section. Sometimes these may be eliminated at slight expense by the construction of false guide walls. As many meters as desired may be mounted on a frame using the slots for guides to lower and hold the meters in the gaging section. If available, a gaging section upstream in the headrace generally is preferred to metering in the power house or too near the unit itself.

Fig. 8 shows the type of velocity distortion obtained when operating downstream from and adjacent to interfering posts and rack supports. It is generally impractical to scan the velocities in a section of this type with great accuracy. Sections located a greater distance downstream from the trash racks give better, although not ideal, metering conditions as shown in Figs. 9 and 10. The distribution shown in Fig. 11 was almost ideal.

Suspension of Meters

If the variation in velocities across the metering section is to be determined by measuring the velocities at a limited number of points, the place at which the meter is operated must be exactly known. Thus, suspension of the meter by cable is in general eliminated as a feasible procedure in precise measurements of flow. Usually suspension from rods will insure the required accuracy in location, although it may be necessary to support the rods from a rigid frame, by stay wires, or a specially designed hoist similar to that shown in Fig. 12.

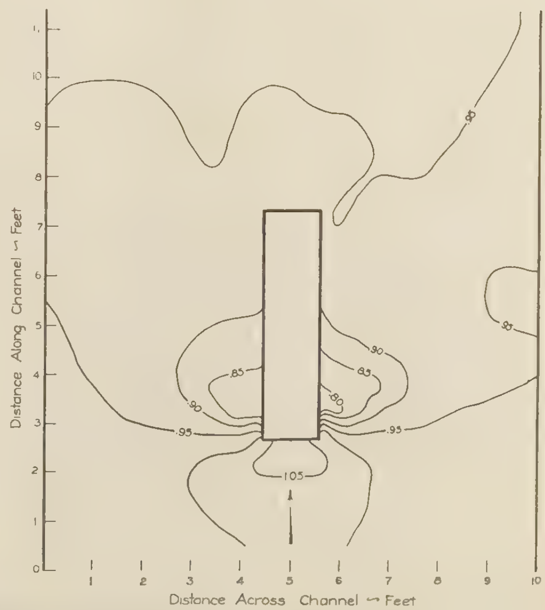
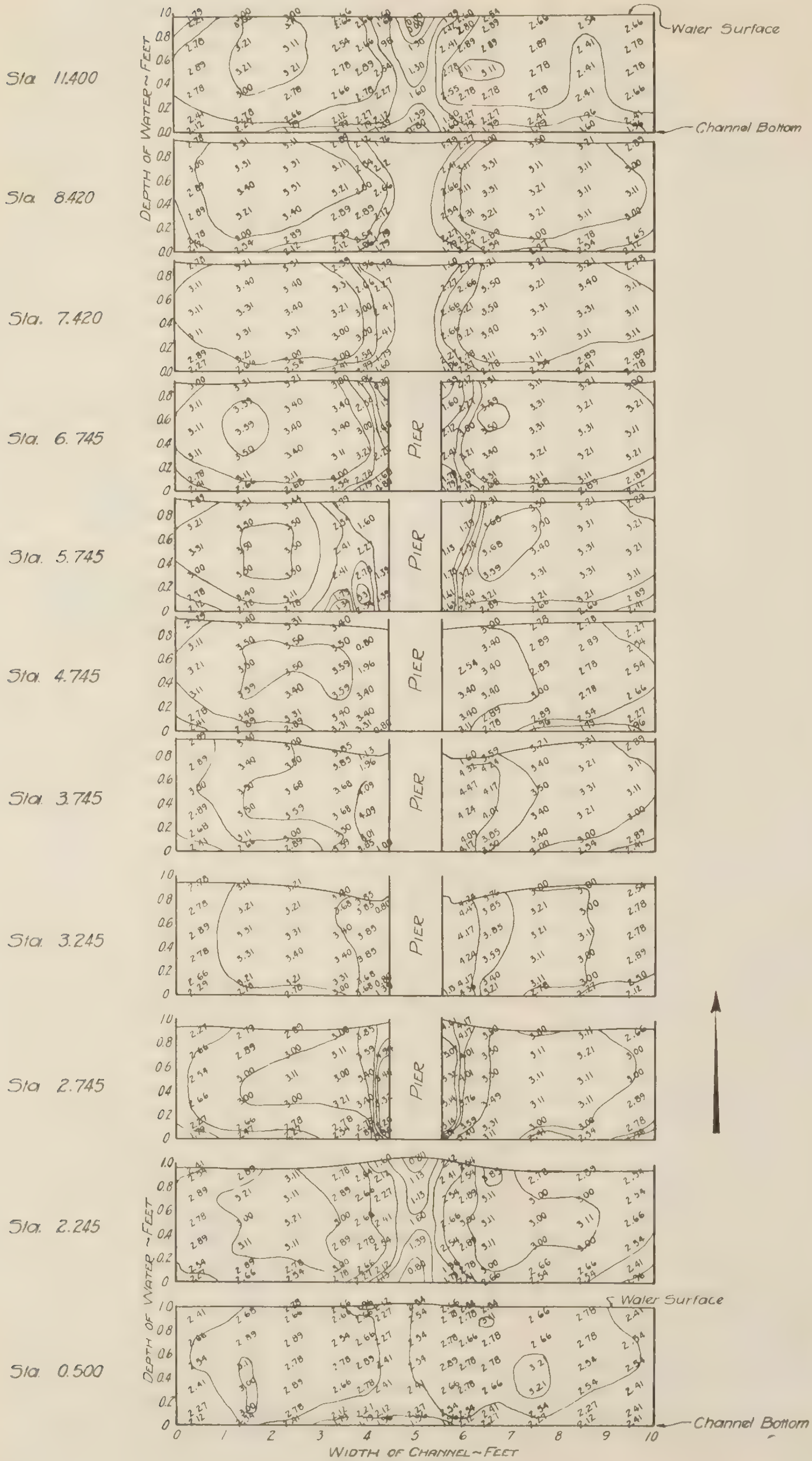


Fig. 13 Water-Surface Contours in Channel Around Pier
(Test No 2; discharge 24.1 cfs.)



When rigidly supported by a rod, meters have generally been found to rotate faster than with cable suspension. Hence, they should be rated with this same type of support.

When steady oblique currents of high velocity are encountered, it may be advisable to allow the meter to swing in line with the filaments of flow making an accurate measurement of the angle, rather than attempting to operate the meter cross-wise with the current.

The obstruction offered by the supporting rods or frame may tend to retard or sometimes even accelerate the rotation of the meter, depending upon the location of the meter with respect to the obstruction. A picture of the alteration in current velocities adjacent to a 14-in. obstruction in a 10-foot channel is shown in Figs. 13 and 14. Current velocities are decreased immediately ahead of the obstruction, but not for a great distance, and there is considerable acceleration of the filaments of flow curving around the obstruction. The possible effect of objects near the meter is so questionable that meters should always be rated in the manner used in the field.

Number and Distribution of Measuring Points

One may compute by formula the number of points required to adequately scan the cross-section of a stream,[15] but consideration must always be given to the configuration of the velocity diagram. Measurements using only one point located at $^2/_{10}$ depth, two points in a vertical at $^2/_{10}$ and $^8/_{10}$ depth or three points in a vertical at $^2/_{10}$, $^6/_{10}$, and $^8/_{10}$ depth are not

[15] Swiss standard for water measurements gives $n = 4.3$ to $7.65 \times \sqrt{A}$, where A is the area in sq ft and n the number of measuring points.

Fig. 14 (Left) Velocity Distribution in Channel Around Pier—Test No. 2

(Single pier in center of channel; width = 1.17 ft, length = 4.67 ft; square nose and tail with nose at sta. 2.63 and tail at 7.30; discharge past pier measured by sharp-crested weir = 24.1 cfs; contours plotted at 0.5 ft per sec interval.)

adequate for precise measurements. In order to reproduce a curved velocity surface by observations at a limited number of points, measurements must be made at a sufficient number of points to define the velocity surface throughout the entire cross-section.

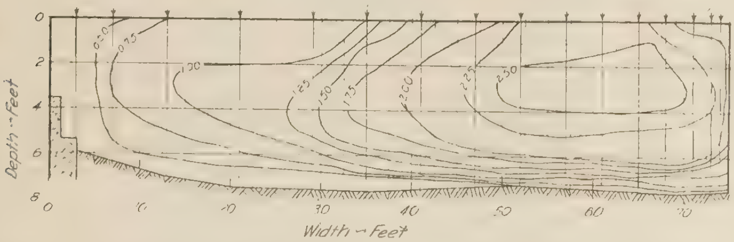


Fig. 15 Discharge Measurement by Current Meter at Section 5 Ft Ahead of Trash Racks
(Velocity contours in ft per sec; discharge = 807 cfs.)

Hence, measuring points should be distributed so that they are more numerous where the curvature in the velocity surface is greatest. Thus, a closer spacing of the verticals and points on the vertical is generally required as one approaches the periphery of the cross-section. An irregular distribution of vertical traverses to meet a distorted condition of flow is shown in Fig. 15. In some instances it has been necessary to use a shrouded meter similar to the Ott meter shown in Fig. 16, or build a special guard around the meter to protect the propeller against injury in sections adjacent to the walls or bottom. The guard shown in Fig. 17 caused a two per cent retardation of the meter, although no portion of the frame was within an inch of the propeller.

The number of verticals is generally reduced to a minimum, consistent with accuracy. Reducing the number of verticals to one-half has been found to double the error, and further reduction to one-quarter has tripled the error. In any event, a preliminary exploration of the section is advisable to fix the meter traverses in their proper locations and to determine the number of points required for each traverse. Care should be exercised that there is no unbalance between the vertical and horizontal spacing of the measuring points.

Small meters are preferred for use in small measuring sections. The United States Engineer Department while engaged in model research at the Iowa Institute of Hydraulic Research developed

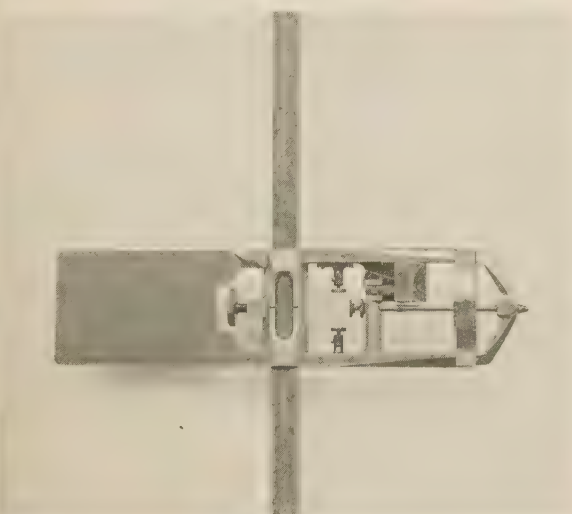


Fig. 16 Small Ott Current Meter—Type X—With Circular Guard

the tiny meter shown in Fig. 18. The friction in this meter has been reduced to the extent that a "straight line" velocity relation is obtained for current velocities as low as one-tenth of a foot per second.

Number of Meters

The simultaneous use of one meter for each vertical traverse is generally the maximum practical desideratum. If only one or a few meters are available, the measurement consumes more time and for precision requires steadier flow. Where conditions are stable, one meter may be permanently installed at a single point as an index to general flow conditions, but the record of an index meter does not constitute a precise measurement of flow.

The mean velocity in a vertical traverse is generally determined by plotting the velocity readings at the specific measuring points. However, the average velocity is sometimes obtained by moving the meter at a constant speed through the vertical—thus obtaining a single "integrated" reading—or by both moving and stop-

Fig. 17 Ott Current Meter—Type IVa—With Special Metal Guard

Fig. 18 Small Meters for Laboratory Service
(Developed in 1931 at Iowa Institute of Hydraulic Research by United States Engineer Dept.)

ping for a fixed period at predetermined equally spaced points, thus obtaining a single "semi-integrated" reading as well as velocity measurements at definite points from which the vertical velocity curve may be drawn. Mr. Strieff has suggested the use of the Tchebycheff formula for determining the proper loca-

tion of any number of points in the vertical, the arithmetic average of which will give the true mean vertical velocity.[16] All of these methods are designed primarily to save labor and time. They are not, however, fool proof against gross error, and to be used with confidence the measuring section must be a good one.

Measuring Turbulent Flow

The existence of turbulence greatly reduces the reliability of current-meter measurements. If the turbulence is mild, the better Ott meters may be trustworthy alone, although the cup meters are not. However, as already mentioned, the use of two types of meters with different registration characteristics is advisable, since the differences between their registration may be used as an index to the amount of the correction to be applied to the more accurate of the two meters.

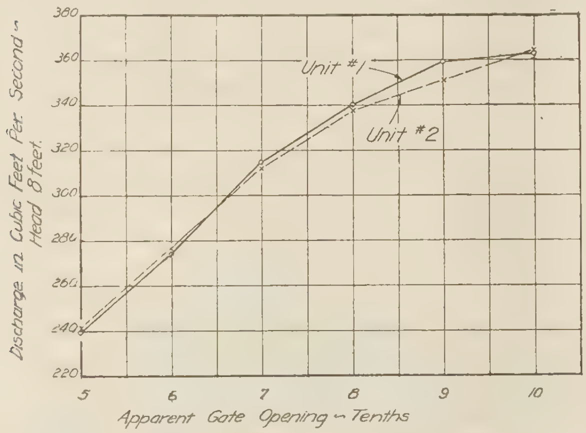


Fig. 19 Discharge Measurements by Current Meter for Two Similar 74-In. Turbines

(Separate settings; metering sections reduced to head of 8 ft.)

Comparative Tests by Current Meter and Other Methods

Many tests have been made to establish the error or validity of current-meter measurements by the simultaneous measurement of the same flow by other methods. Although significant and interesting, the results are not always conclusive, since either the technique of using the current meter may be questioned or errors may be involved in the standard of comparison itself. Thus F. P. Stearns,[17] in comparing current-meter measurements with a weir, found that the degree of agreement depended upon the use of the meter.

Perhaps only those who have obtained good comparative results with current meters have ventured to publish the fact. At least, engineering literature contains many verifications of the reliability of current-meter measurements. The following extracts from a few may be worthy of note.

E. C. Murphy[18] concluded that the Price meter can be used under ideal conditions to measure discharge within 1 or 2 per cent, but bad use of the meter under abnormal conditions produced departures of 40 per cent from the weir discharge. In a series of 50 measurements in the Cornell Laboratory Canal, measurements by Haskell and Price meters showed a maximum variation of 4.8 per cent, but twenty of the tests showed differences of less than 1 per cent.

W. B. Gregory[19] obtained a maximum variation of 2 per cent and an average variation of 0.1 per cent when compared with a pitot tube in measuring pump discharge.

The current-meter measurements made at Massena by B. F. Groat[20] agreed with the hydrochemical gagings with an error of less than 1 per cent. He concluded that results of a "remarkably high degree of precision can be obtained, even under very unfavorable hydraulic conditions, with meters of properly related types in conjunction with an intelligent statistical study of their performance."

Robert E. Horton[21] states that the current meter has been a much abused instrument, and under suitable conditions it may quite certainly give results accurate within less than 1 per cent.

In 1914, A. Strieff made measurements of flow with Ott current meters at the Croton, Michigan, power house all of which agreed with hydrochemical gagings within 1.3 per cent.

F. C. Scobey measured discharge through wood-stave pipe[22] simultaneously by color, weir and current meter, with differences varying from zero to 6 per cent.

D. L. Yarnell made 102 comparative discharge measurements with pitot tube, weir and current meter during the period 1922–1924 at the University of Iowa Laboratory.[23] From those tests he concluded that the current meter can be used with less error than the pitot tube, and with care the error may be reduced below 2 per cent.

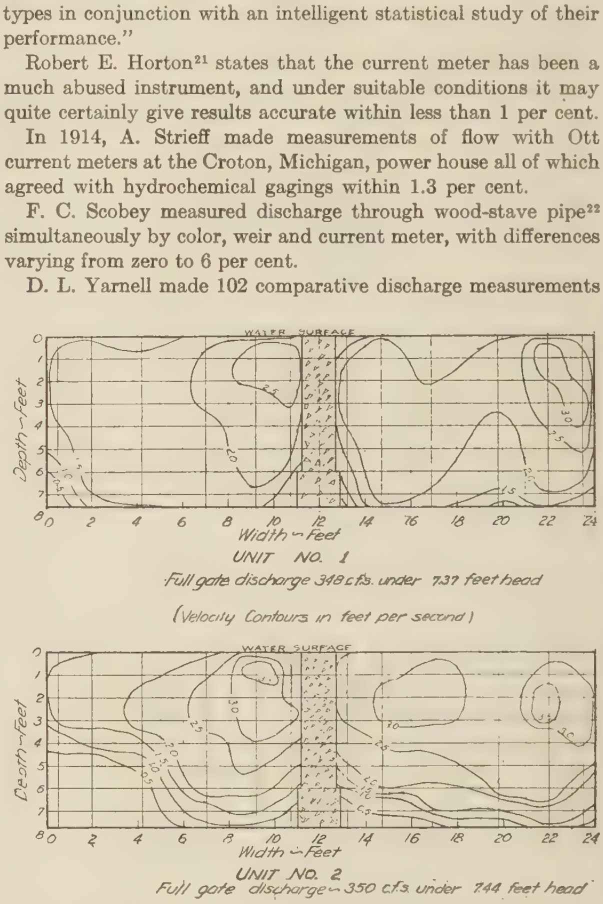


Fig. 20 Discharge Measurements by Current Meter in Separate Intake Flumes Leading to Two Similar 74-In. Turbines at Sections 6 Ft Downstream From Trash Racks

(Velocity contours in ft per sec; both sections give identical discharge of 362.5 cfs under head of 8 ft.)

The recent comparative flow measurements of Carl Rohwer[24] show the magnitude of the errors that might be anticipated with different methods of using the meter. It is unfortunate that most of the comparisons are based upon flow over an uncalibrated contracted weir and that the "multipoint method" was not properly applied. However, his conclusions agree with those

[16] Trans. A.S.C.E., vol. 95, 1931, pp. 859 and 860.

[17] Ibid., 1883, pp. 301–338.

[18] Water Supply and Irrigation Papers 47, 64, U. S. Geological Survey; also Trans. A.S.C.E., vol. 1902, pp. 370–391.

[19] Trans. A.S.C.E., vol. 28, pp. 745–769.

[20] Trans. A.S.C.E., 1916, p. 1233.

[21] Ibid., 1916, p. 1283.

[22] Bull. 376, U. S. Dept. of Agric.

[23] "Comparison of Discharge Measurements by Weir, Pitot Tube, and Current Meter" (unpublished thesis).

[24] Tech. Bull. No. 3, Colorado Agric. College.

from other investigations, that reasonably accurate measurements can be made by the use of the current meter.

Many European tests have confirmed the reliability of flow measurements by current meter mostly under ideal conditions. Perhaps the experiments of O. Kirschmer and B. Esterer[25] are the most convincing. All measurements with the Ott current meter checked reliable volumetric measurements within a maximum error of 1 per cent.

Fig. 19 shows the results of flow measurements made by current meter on two similar 74-inch water turbines in different wheel pits, requiring the use of individual metering sections. The velocity contours for full gate at the two sections are shown in Fig. 20. The close agreement, which could hardly be improved upon by any other method of water measurement, cannot be the result of an accident.

Precision in Water Measurements

Perhaps the word "precise" as applied to water measurements is merely a relative term. As applied to a current-meter measurement, the measure of precision no doubt depends upon the accuracy obtainable with other methods, all of which must ultimately be gaged by the measurement of the actual volume or weight of water concerned. However, there are no scales and but few measuring basins large enough to hold the discharge commonly measured with meters.

Even in the laboratory, errors of 1 and 2 per cent are commonly made by inexperienced engineers in so simple an experiment as checking a gravimetric measurement against a volumetric test. It is not surprising, therefore, to encounter greater errors than these in the inexperienced application of the more complicated methods of measurement of larger flows in the field, where the current meter has sometimes been selected as the last alternative where no other method can be applied.

Under ideal conditions, the best current meters can be used to secure precise measurements of flow, dependable within 2 per cent, and if used intelligently in the hands of experts, the deviation from the true value should not exceed 1 per cent. If conditions are not ideal, the degree of precision with current meters may still be better than with any other known method, and the accuracy of the result will depend upon the extent to which the metering conditions depart from the ideal.

[25] *Zeit. V.D.I.*, 1930, vol. 74, no. 44, p. 1499.

Report on Oil-Engine Power Cost for 1933[1]

THIS report presents information on the production cost of oil-engine power plants. Production cost in the meaning of this report is defined as consisting of the following items: fuel cost; lubrication cost; cost of attendance and superintendence; cost of supplies and miscellaneous; cost of engine and plant repairs.

The report includes information from 156 oil-engine generating plants, containing 398 engines, totaling 216,010.5 rated bhp. The total net output for the 156 plants in this report amounted to 259,209,519 kwhr. The coverage of this report as compared to that of previous reports is shown by the following tabulation:

Year of report.	1929	1930	1931	1932	1933
Number of plants	36	94	119	140	156
No. of engines...	107	283	330	377	398
Total rated bhp.	68,775	161,583	190,768	213,910.5	216,010.5
Total output, net kwhr.	134,766,761	309,369,930	333,066,644	282,466,690	259,209,519

The engines listed in the report are full-Diesel, vertical type and direct-connected to generators, unless otherwise noted in Table III. All Diesel plants listed are located in the United States.

Plant Numbers. The system used in former reports of designating plants by numbers has been retained. Numbers identifying plants previously reported correspond to the same plants in this report.

Period Covered. All but two of the plants of this report submitted data for a period of exactly 12 months each. Of the two exceptions, one submitted for a period of 9.3 months; the other for a period of 7.2 months.

Bases for Costs and Performances. Unit costs referred to in this report were calculated on the basis of net kilowatt-hours. The net kilowatt-hour output is found by subtracting the power used for plant auxiliaries and station lights from the total gross output of the plant.

Figures given for power output per gallon of fuel oil and of lubricating oil were calculated on the basis of the gross output of the individual units and plants.

Formulas defining running-engine-capacity factor, running-plant-capacity factor, annual-plant-load factor, and plant-service factor are as follows:

Running-engine-capacity factor, per cent

$$= \frac{\text{Engine output in gross kwhr} \times 100}{\text{Kw rating} \times \text{number of hours operated}}$$

Running-plant-capacity factor, per cent

$$= \frac{\text{Plant output in gross kwhr} \times 100}{\text{Total rated kwhr of individual units}}$$

Annual-plant-load factor, per cent

$$= \frac{\text{Plant output in gross kwhr} \times 100}{\text{Peak load in kw} \times \text{number of hours in period}}$$

Plant-service factor, per cent

$$= \frac{\text{Total rated kwhr of individual units} \times 100}{\text{Total installed kw} \times \text{number of hours in period}}$$

The expression "rated kwhr" refers to the kilowatt rating of an engine-generator set multiplied by the number of hours operated. For example, if a unit having a rating of 200 kw was operated 4000 hours, the rated kwhr equals 800,000, no matter what the actual output may have been. Thus the denominator of the expression for "Running-plant-capacity factor" and likewise the numerator for the "Plant-service factor" are arrived at by totaling the rated kilowatt hours of all plant units. In this report, the kilowatt rating of an engine-generator set is considered equal to: Rated bhp $\times$ 0.746 $\times$ 0.9.

In the strict sense of its definition, the annual-plant-load factor cannot be correctly applied to data covering any period other than one year. However, the committee extended the application of this to plants operated 8760 hr. plus or minus 2 per cent, using the actual number of hours in the denominator in each case.

The formula for "Plant-service factor" requires further explanation for special cases. The expression is an index of the actual number of hours of operation as compared with the total number of hours installed for operation. Therefore, when some units have been installed for longer periods than have others in the same plant, account must be taken of the fact in the calculation. For example, assume that a plant is reported for a twelve-month period, during which time one unit rated at 200 kw, installed before the start of the period, was operated 5000 hours. Six months after the start of the period, a unit rated at 300 kw was installed, and subsequently operated 2500 hours. The plant-service factor in per cent is therefore:

$$\frac{200 \times 5000 + 300 \times 2500}{200 \times 8760 + 300 \times 4380} \times 100$$

Since the 300-kw unit was not installed during the entire 8760 hours, but only for 4380 hours, this adjustment must be made.

Fuel and Lubricating-Oil Data. The lubricating-oil economies of 120 plants generating 95 per cent or more of their outputs by means of full-Diesel units are shown graphically in Fig. 1, in which the kwhr output per gallon of lubricating oil is plotted against running plant capacity factor. (Five of the full-Diesel plants did not report unit hours of operation, and running-capacity factor could not be calculated for these. One full-Diesel plant operated only a nominal length of time and did not require any lubricating oil. The amount of lubricating oil for one full-Diesel plant was not available.) Fuel-oil economies of 122 full-Diesel plants are shown graphically in Fig. 2, in which the gross kwhr output per gallon of fuel oil is likewise plotted against the running-plant-capacity factor. (The same five plants which did not report units hours of operation are not included.) The values plotted in Fig. 2 are not corrected for the heat content of the fuel or for altitude. The lubricating-oil and fuel-oil economies of 24 plants generating more than 5 per cent of their output by means of semi-Diesel units are shown in Figs. 3 and 4, respectively. (Five plants generating more than 5 per cent of output by semi-Diesel units did not report unit hours of operation, and running-capacity factors could not be calculated for these.)

The type of the plant was judged to be that of the engines generating 95 per cent or more of the gross output. The following types of plants are illustrated in Figs. 1 to 4, inclusive:

Diesel, four-stroke cycle, air injection

Diesel, four-stroke cycle, mechanical injection

Diesel, two-stroke cycle, air injection

Diesel, two-stroke cycle, mechanical injection, separate scavenging

[1] Submitted by the Subcommittee on Oil-Engine Power Cost, Oil and Gas Power Division, A.S.M.E.; H. C. Major, chairman, Committee of Public Utilities, Municipal Bldg., Rockville Center, L. I., N. Y.

Presented at the Seventh National Oil and Gas Power Meeting, State College, Pa., June 20–23, 1934, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

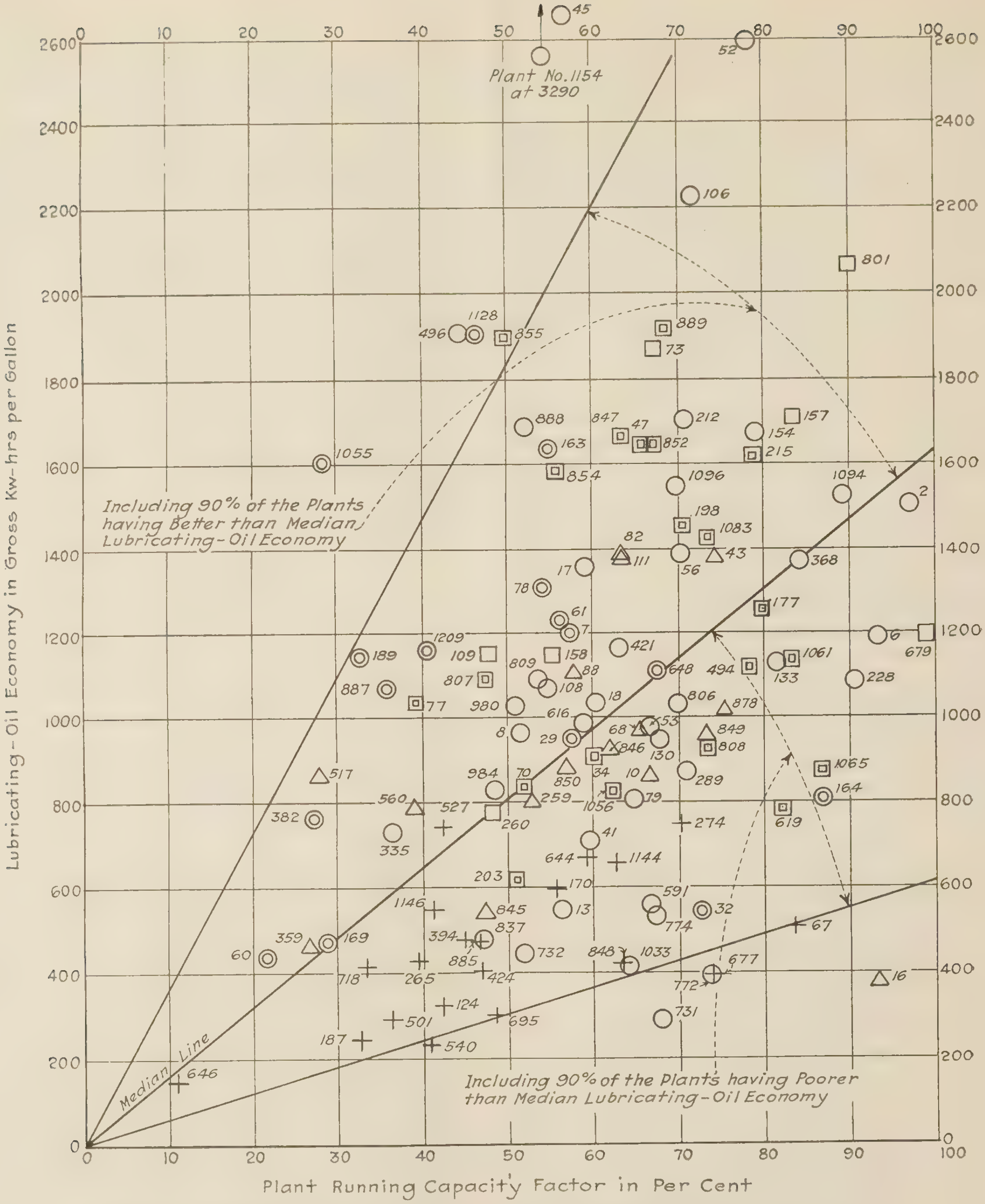


FIG. 1. LUBRICATING OIL ECONOMIES OF 120 FULL DIESEL PLANTS, NOT INCLUDING 5 FULL DIESEL PLANTS, RUNNING CAPACITY FACTORS FOR WHICH ARE NOT AVAILABLE, NOR ONE SUCH PLANT WHICH RAN A NOMINAL NUMBER OF HOURS AND REQUIRED NO NEW LUBRICATING OIL, NOR ONE FOR WHICH LUBRICATING OIL GALLONAGE IS NOT AVAILABLE

(For Key to Plant Symbols see Fig. 2)

Diesel, two-stroke cycle, mechanical injection, crankcase scavenging

Mixed-type full Diesel

Mixed Diesel and semi-Diesel.

A median line was drawn on each chart, the number of points above the line being equal to the number below. High and low boundary lines were drawn to include all but 10 per cent of the plants on the high and low sides, respectively.

Unless it is otherwise noted in Table III plants received fuel oil in tank cars.

All fuel- and lubricating-oil costs include costs for the handling of oil from the cars to the tanks.

Cooling Water. The various water-cooling systems are indicated by the following symbols:

System A—Raw water going to waste after one pass

System B—Raw water recirculated after passing over cooling tower or spray pond

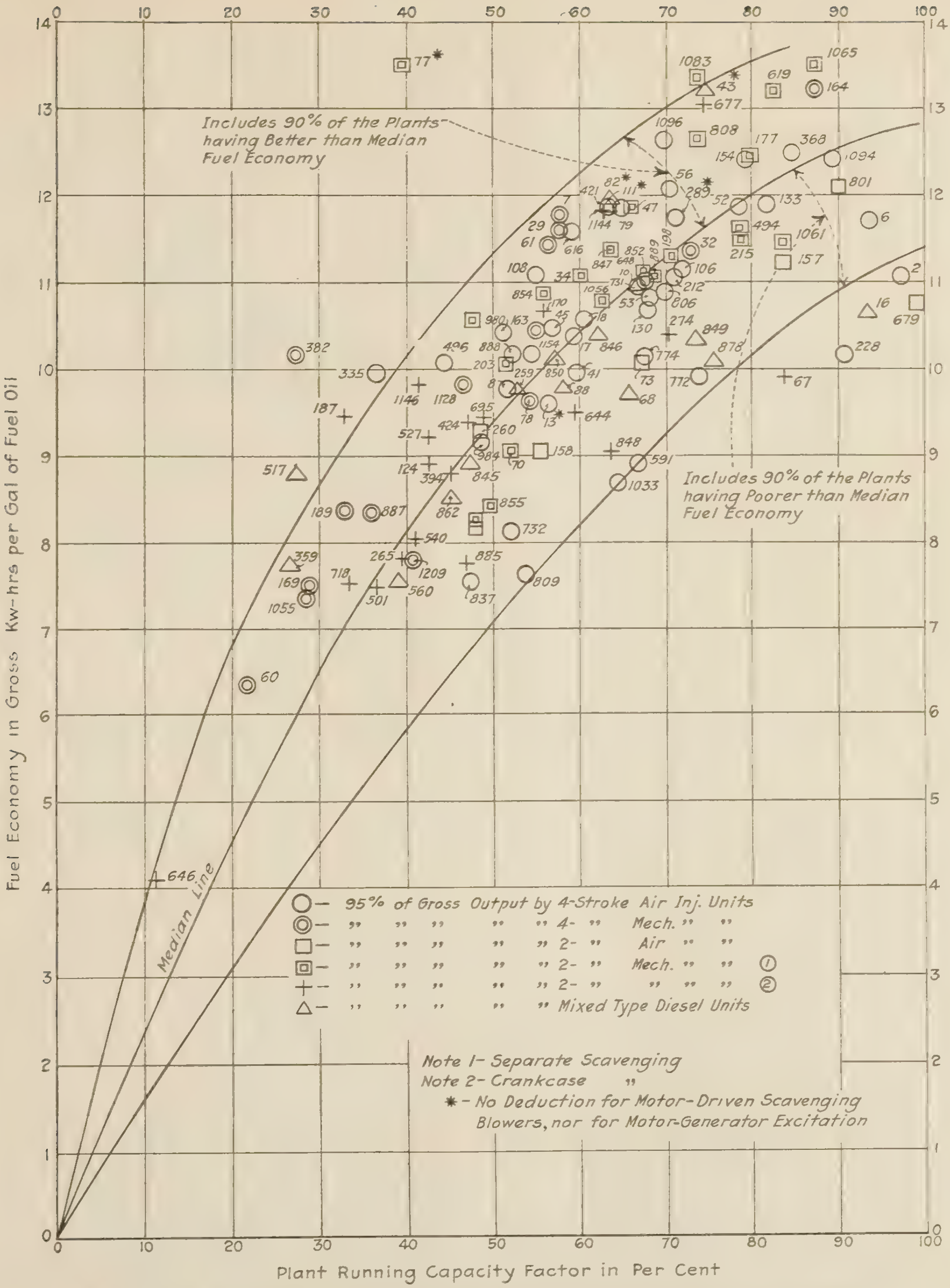


FIG. 2. FUEL ECONOMIES OF 122 FULL DIESEL PLANTS, NOT INCLUDING 5 FULL DIESEL PLANTS, RUNNING CAPACITY FACTORS FOR WHICH ARE NOT AVAILABLE
(Not Corrected for Heat Content of Fuel nor for Altitude)

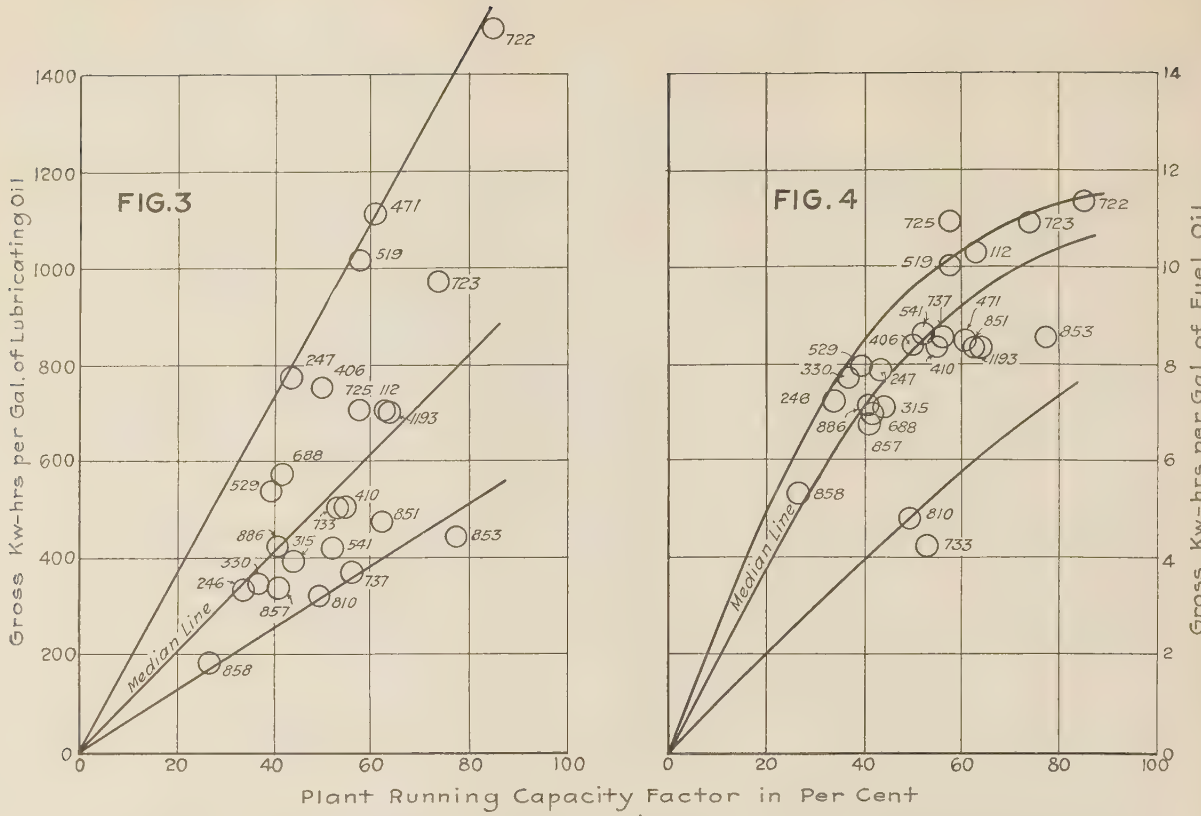
System C—Soft water continuously recirculated, cooled by raw water going to waste after one pass through heat exchanger

System D—Soft water continuously recirculated, cooled by raw water also recirculated after cooling by cooling tower or spray pond

System E—Engine circulating water cooled by radiator and fan

System F—Any of the foregoing systems with engine circulating water treated (added as a suffix)

Enforced Shutdowns. The term "enforced shutdown" is defined as any stoppage caused by actual or imminent engine trouble. The duration of an enforced shutdown is the time elapsing from the shutdown of the engine to the time at which the engine is again ready for service. A



FIGS. 3 AND 4. FUEL AND LUBRICATING OIL ECONOMIES OF 24 PLANTS GENERATING MORE THAN 5 PER CENT OF OUTPUT BY SEMI-DIESEL UNITS, NOT INCLUDING 5 SUCH PLANTS, RUNNING CAPACITY FACTORS FOR WHICH ARE NOT AVAILABLE

prearranged shutdown for maintenance work is not considered an enforced shutdown. Regular maintenance time where listed is the total time put in on regular maintenance work whether or not the units were actually needed during the time.

Peak Loads. The peak loads presented in the report are the highest average loads sustained for 15 minutes, unless otherwise stated in Table III.

Repair Costs. All costs for repairs whether to engines only or to all other plant equipment, listed in Table I, include the cost of materials delivered at the plant in question and the cost of any extra labor employed for the purpose of making these repairs. Unless otherwise noted, however, these costs do not include any charges for work done by regular attendants. Correspondingly, unless otherwise noted, the costs given in Table I for attendance and superintendence have not been subject to deduction because of repair work done by the regular attendance crews.

Attendance and Superintendence. Table III presents data on the number of shifts per year, the length of shifts and the number of attendants per shift, where these data are available. Table III also presents the net kwhr output per man hour of attendance for those plants operated by full-time attendance and also for those plants having part-time attendance, provided only one man out of at least four works part time.

Supplies and Miscellaneous. Supplies in the meaning of this report include those items used in the power-generating plant which are consumed in the operating process such as: waste, packing, wipers, gage glasses, gaskets, bolts, screws, nails, dynamo and motor brushes, cans for containing rags and waste, transformer oil and hand oil cans. The term "miscellaneous" as used in this report refers to such items as expenditures for lighting, heating, cleaning systems, fire-protection systems, janitor's supplies, ice water, meals and carfare, stationery, telephone and toilet service and care of streets, yards and sidings.

Type of load. The terms used for type of load are defined as follows:

Complete Power—Plant run regularly alone when needed, without assistance from any base or peak-load service

Base Load—Plant run at substantially full load whenever its capacity can be used; usually supplemented by a peak-load service. When full or nearly full capacity cannot be used, plant is shut down

Peak Load—Plant run only when load exceeds capacity of regular source of power

Standby—Plant run only when regular source of power is interrupted.

For this investigation, the committee requested information also on the type of power supplemented by base load, peak load, and standby plants. Information obtained in accordance with this request is presented in Table I.

Total Production Costs. Total production costs for 154 plants reporting for one year each (plus or minus one month) are shown graphically on logarithmic coordinates in Fig. 5. In this chart total production cost in mills per net kwhr is plotted against specific output, or the output in net kwhr per year per kw of installed capacity.

Calculations. The committee was assisted in its work by Messrs. Robert T. Brown and F. E. Bunbery, Jr.

SUBCOMMITTEE ON OIL-ENGINE POWER COST

H. C. Major, Chairman	Howard McCurdy
M. J. Reed, Secretary	A. B. Morgan
L. R. Ford	L. H. Morrison
W. G. G. Godron	Lee Schneitter
K. M. Irwin	P. H. Schweitzer
Edgar J. Kates	H. C. Thuerk
H. C. Lenfest	C. A. Trimmer

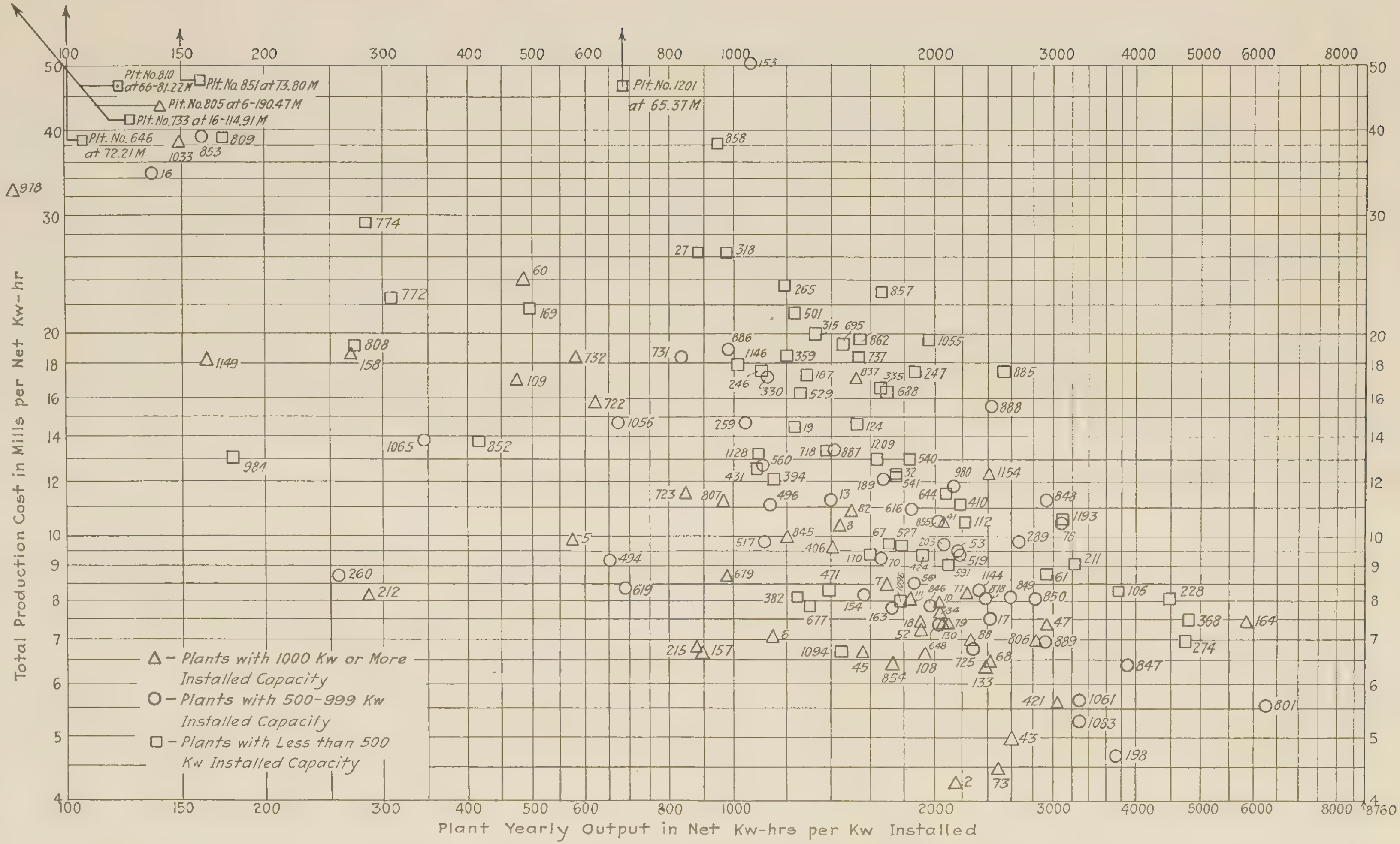


FIG. 5. TOTAL PRODUCTION COSTS FOR ALL PLANTS REPORTED, WITH THE EXCEPTION OF 2 WHICH OPERATED FOR PERIODS OF LESS THAN 11 MONTHS—MILLS PER NET KW HR.

TABLE I—INFORMATION ON PRODUCTION COST (Page 1)

Plant Number	Character of Plant (See Notes)	Type of Load (See Notes)	Number of Engines	Total Installed B.H.P.	Total Installed K.V.A.	Total Plant Hours Operated in Reported Period	Number of Months in Reported Period	Total Gross Output—K.W. Hrs.	Determination of Gross K.W. Hrs. (See Notes)	Total Net Output—K.W. Hrs.	Determination of Net K.W. Hrs. (See Notes)	Percent of Gross K.W. Hrs. for Plant Purposes	Annual Plant Load Factor (See Text)	Running Plant Capacity Factor (See Text)	Plant Service Factor (See Text)	Average Cost of Fuel Oil—Cents per Gallon	Average Cost of Lubricating Oil—Cents per Gallon	Costs per Net K.W. Hr.—Mills: Fuel Oil Cost	Lubricating Oil Cost	Attendance Cost Including Superintendence	Cost of Supplies and Misc., including Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Combined Cost of All Repairs, Supplies and Miscellaneous	Total Production Cost	Plant Number
43	U	C	9	15,640	14,850	8,760	12	30,795,736	M	27,434,541	A	10.9	55.1	74.3	45.1	3.39	28.8	2.88	0.23	0.77	0.09	0.75	0.23	1.07	4.95	43
82	M-W	C	7	8,960	8,102	8,760	12	9,995,550	M	9,014,095	M	9.8	34.0	63.2	30.0	4.24	58.5	3.94	0.47	2.74*a*	0.87	1.37*a*	1.45*a*	3.69	10.84	82
52	M	C	5	7,445	6,380	8,760	12	9,949,800	M	9,530,892	M	4.2	37.6	78.3	29.0	4.26	58 6	3.75	0.24	2.43	0.21	0.48	0.09	0.78	7.20	52
73	M-W	C	4	5,000	4,500	8,760	12	8,921,600	M	8,379,100	M	6.1	44.3	67.2	45.1	1.60	56.0	1.69	0.32	2.03	0.08	0.33	0.02	0.43	4.47	73
45	M	C	5	4,250	3,625	8,760	12	4,984,325	M	4,471,550	M	10.3	35.6	56.9	35.1	3.10	37.2	3 30	0.16	2.56	0.07	0.39	0.15	0.61	6.63	45
111	M	C	4	3,675	3,160	8,760	12	5,135,900	M	4,543,778	M	11.5	39.1	63.2	37.6	3.45	49.8	3.29	0.41	3.27	0.44	0.25	0.35	1.04	8.01	111
130	M	C	4	3,600	3,150	8,760	12	5,238,400	M	4,919,360	M	6.1	43.7	67.8	36.5	4.27	61.4	4.27	0.69	1.50	0.43	0.37	0.10	0 90	7.36	130
157	U	V-T	2	3,520	3,000	5,840	12	2,162,100	M	2,122,944	M	1.8	10.7	83.6	12 5	4.48	52.6	4.07	0.31	1.56	0.32	0.32	0.02	0.66	6.60	157
2	M-W	B&P-T	3	3,450	3,000	2,266	12	5,071,720	M	4,980,440	M	1.8	24.6	97 3	25.7	1.92	21.5	1.77	0.15	1.82	0.11	0.36	0.04	0.51	4.24	2
164	I	B-Z	4	3,360	4,000	8,760	12	13,784,200	M	13,289,000	E	3.6	....	87.0	80.1	4.01	22.5	3.15	0.29	1.32	0.24	1.80	0.60	2.64	7.41	164
77	U	C-Z*b*	1	3,000	2,812	8,760	12	5,790,900	M	4,511,158	A	22.1	38.9	39.3	83.5	4.91	38.9	4.67	0.48	1.87	0.35	0.83	0.01	1.19	8.21	77
109	M	S-H	3	2,925	2,450	8,760	12	959,960	M	931,425	M	2.9	9.5	47.9	11.7	5.95	81.8	7.51	0.73	6.85	0 90	0.80	0.10	1.80	16.89	109
7	M	C	5	2,730	2,625	8,760	12	3,359,900	M	3,114,320	M	7.3	41.6	57.5	36.4	3 80	30.0	3.48	0.27	3.04	0 35	0.72	0.58	1.65	8.44	7
732	U	P-T	5	2,520	2,050	8,760	12	1,222,560	M	988,290	M	19.2	10.0	52.0	15.8	2.62	45.0	3.99	1.25	8.32	1.55	2.82	0.35	4 72	18 28	732
978	U	S-	3	2,520	2,100	.....	12	184,300	M	142,039	M	22.9	1.9	....	....	3 97	49.6	4.00	0.47	18.09	4.04	5.74		9.78	32.34	978
679	M	P-H	2	2,500	2,130	2,264	12	1,677,900	M	1,639,420	M	2.3	10.4	99.2	11.5	5.28	44.0	5.03	0.38	1.74	0.84	0.70	0	1.54	8 69	679
60	I	C	3	2,400	2,025	8,760	12	939,700	M	777,920	E	17 2	20.6	21.6	30.8	5 16	55 1	9.83	1.52	11.34	0.25	0.96		1.21	23.90	60
1149	U	S-	2	2,400	2,091	.....	12	290,760	M	262,329	M	9 7	2.0	....	....	3.90	55.0	3.68	0.21	11.44	2.00	0.81		2.81	18.14	1149
41	M-W	C	3	2,370	1,800	8,760	12	3,329,790	M	3,279,790	E	1.5	31.7	59.7	40.0	4.37	46 1	4.45	0.66	4.44	0.39	0.17	0.39	0.95	10.50	41
723	U	S-T	4	2,370	2,010	2,242	12	1,411,510	M	1,349,830	M	4.4	10.2	73.8	13.7	4.41	49.7	4.24	0.53	4.59	0.72	1.11	0.28	2.11	11.47	723
34	M-W	C-Z*b*	3	2,250	1,920	8,760	12	3,149,100	M	3,101,023	M	1.5	44.9	60.2	39.5	4.31	26.7	3.95	0.30	2.15	0.13	1.14		1.27	7.67	34
79	M	C	5	2,170	1,858	8,760	12	3,230,400	M	3,065,966	A	5.1	41.0	64.8	39.1	3 23	39.9	2.88	0.52	3.12	0.43	0.39	0	0.82	7.34	79
5	U	S-	3	1,160	.....	.....	12	918,180	M	834,039	M	9.2	7.0	....	....	4.02	47.6	4.59	0.54	3.65	0.45	0.65		1.10	9.89	5
6	U	C	4	2,100	.....	.....	12	1,652,500	M	1,616,773	M	2.2	12.7	93.5	14.3	4.34	50.2	3 79	0.43	1.67	0.32	0.83		1.15	7.04	6
68	M-W	C	4	2,060	1,744	8,760	12	3,516,800	M	3,347,210	M	4.8	59.9	65.4	44.4	3.73	46.2	4.02	0.50	1.29	0.13	0.46	0.04	0.63	6.44	68
133	I	B-Z	2	2,000	1,376*d*	3,561	12	3,224,550	M	3,216,935	E	0.3	26.8	81.6	33.6	4.81	37.9	4.05	0.34	1.49	0.07*c*	0.37	0	0.44	6.32	133
806	U	B-T	3	2,000	1,758	8,760	12	3,981,520	M	3,814,300	M	4.2	49.9	69.9	48 4	2.10	66.6	2.01	0 68	2.24	1.00	0.22	0.81	2.03	6 95	806
29	I	C	3	1,980	1,689	1,800	9.3	926,340	M	886,688	M	4.3	...	57.6	17.6	4.75	67.4	4.27	0.74	6.39	0.27	0	0	0.27	11.67	29
215	U	S-H&T	2	1,960	1,690	8,760	12	1,194,900	M	1,163,860	E	2.6	11.4	78.9	13.1	4.49	50.7	4.02	0.32	1.44	0.55	0.46	0	1.01	6.79	215
807	U	P-T	4	1,885	1,572	8,760	12	1,416,913	M	1,223,713	M	13.6	32.3	47.5	26.9	3.56	80.5	3.90	0.86	5.06	0.88	0	0.44	1.32	11.15	807
108	M-W	C	3	1,875	1,601	8,760	12	2,548,000	M	2,440,000	M	4.3	36.9	54.9	42.1	2.31	52.0	2.18	0.51	2 94	0.61	0.23	0.10	0.94	6.57	108
837	U	C	5	1,875	1,625	8,760	12	2,064,771	M	1,920,591	M	7.0	39.3	47 1	39.8	2.51	40.4	3.57	0.90	6.01	0.51	5.15	0 98	6.64	17.12	837
1033	U	P&S-T	4	1,865	1,300	....	12	206,550	M	186,791	..	9.5	2.8	64.1	2.9	4.17	30.2	5.31	0.80	21.35	3.76	3.17	3.87	10.80	38.26	1033
421	M-W	B-G	2	1,800	1,576	8,760	12	3,802,600	M	3,689,473	E	3.0	....	63.1	....	2.32	53.0	2.02	0.47	2.85	0.16	0.07	0	0.23	5.57	421
845	U	C	3	1,770	1,500	8,760	12	1,489,775	M	1,434,575	M	3 7	36.2	47.3	30.2	3.93	38.6	4.57	0.74	2.97	0.44	1.26	0	1 70	9.98	845
854	U	B-T	3	1,770	1,500	8,760	12	2,177,480	M	2,064,467	M	5.2	28.3	55.8	37.5	3.98	36.5	3.87	0.24	1.76*e*	0.32	0.15	0.09	0.56	6.43	854
158	U	P&S-T	1	1,760	1,500	2,920	12	343,172	M	317,690	M	7.5	3 9	55.4	6.0	6.06	59.3	7 24	0.56	5.35	4 90	0 07*f*	0.39	5.36	18.51	158
212	W	S-T	2	1,750	1,342	8,760	12	337,200	M	336,189	E	0.3	6 8	70.8	4.6	3.60	49 0	3.27	0.29	2.17	0.30	2.07	0	2.37	8 10	212
722	U	S-T	4	1,705	1,450	8,760	12	774,780	M	709,180	M	8.5	8 0	84.9	9.1	4.53	77.2	4.36	0.56	7.98	1.25	1.26	0.32	2.83	15.73	722
805	U	S-Z	2	1,680	1,400	8,760	12	7,870	M	6,585	M	16.3	0.2	48.1	0.2	2.76	....	4.00	0	182.48	2.64	0	1.36	4.00	190.47	805
18	U	C	3	1,650	.....	.....	12	2,205,070	M	2,112,805	M	4.1	26.8	60.4	37.6	4.22	49.9	4.16	0.50	1.74	0.31	0.72		1.03	7.44	18
88	M-W	C	4	1,620	1,318	8,760	12	2,532,910	M	2,470,900	M	2.5	42.8	57.9	45.9	3 04	52.1	3.18	0.48	2.84	0 36	0 10	0	0 46	6 96	88
8	M-W	C	3	1,560	1,350	8,760	12	1,554,430	M	1,511,411	E	2.8	....	51.6	32.8	3.44	40.0	3 64	0.43	4.84	0.26	1.07	0.08	1.41	10.32	8
406	M	C	4	1,560	1,300	8,760	12	1,589,240	M	1,482,043	E	6.8	42 7	50.0	34.6	3.51	58.4	4.48	0.83	3 05	0.71	0 24	0.28	1 23	9.59	406
10	W	C	2	1,500	1,250	6,199	12	2,080,220	M	2,057,220	E	1.1	54.0	66.6	35.4	1.82	21.0	1.68	0.25	3.72*g*	0 47	0.74	1.07	2 28	7.92	10
47	U	C-T	1	1,500	1,250	8,760	12	3,021,340	M	2,967,310	M	1.8	32.9	65.9	52 0	6.01	45.1	5.15	0.28	1.18	0.49	0.26	0	0.75	7.36	47
1154	M	C	2	1,500	1,500	8,760	12	2,455,900	M	2,433,000	A	0 9	37.4	54.3	51.2	5 51	71.3	5.47	0 22	6.16	0 23	0.12	0 05	0 40	12 25	1154
289	M	C	4	1,465	1,232	8,760	12	2,747,030	M	2,625,010	E	4 5	38 3	71.0	44.9	4 30	52 0	3.83	0.62	4.29	0 33	0.54	0 26	1.13	9 87	289
496	M	C	3	1,450	1,240	8,760	12	1,201,175	M	1,108,150	M	7.7	21 1	44 4	31.7	4 08	64.8	4.39	0.37	4.98	0 89	0.44	0	1.33	11 07	496
850	U	B-T	2	1,440	1,200	8,760	12	2,844,460	M	2,736,620	M	3.8	33.2	56.9	59.0	4 69	39.0	4.81	0.46	1.83	0 30	0.61	0.01	0.92	8.02	850

849	U	P-T&Z	2	1,410	1,200	8,760	12	2,516,180	M	2,463,870	M	2.1	30.3	73.2	41.5	5.01	35.2	4.94	0.38	1.98	0.12	0.64	0	0.76	8.06	849
154	U	C	3	1,400	.....	.....	12	1,513,170	M	1,483,854	M	1.9	30.3	79.2	23.2	3.87	52.8	3.18	0.33	2.81	0.31	1.48		1.79	8.11	154
163	I	...	3	1,400	1,311	8,760	12	1,771,725	M	1,636,205	E	7.7	20.2	55.0	39.1	3.44	26.3	3.58	0.17	1.24	0.74	2.07		2.81	7.80	163
198	U	P-T	1	1,400	1,392	5,976	12	3,666,420	M	3,514,032	A	4.2	41.9	70.6	63.1	3.52	15.3	3.26	0.11	0.77	0.11	0.42		0.53	4.67	198
517	M	C	2	1,375	1,250	8,760	12	1,122,560	M	1,034,979	E	7.8	34.2	27.7	50.1	3.65	60.6	4.51	0.76	4.19	0.30	0.07	0.01	0.38	9.84	517
888	U	C	3	1,375	1,200	8,760	12	2,326,490	M	2,252,600	M	3.2	31.6	52.1	55.2	4.69	51.9	4.76	0.32	5.45	2.02	2.52	0.68	5.22	15.75	888
725	U	B-T	4	1,310	1,107	8,760	12	2,071,200	M	2,013,550	M	2.8	37.5	57.8	46.5	3.59	55.1	3.38	0.80	2.19	0.32	0.04	0.02	0.38	6.75	725
886	U	C	4	1,305	1,090	8,760	12	913,325	M	865,747	M	5.2	34.0	40.7	29.3	4.74	50.6	7.00	1.26	5.88	1.71	2.76	0.13	4.60	18.74	886
13	M-W	C	3	1,225	1,000	8,760	12	1,300,700	M	1,153,244	M	11.3	39.6	56.4	32.0	4.72	41.9	5.55	0.86	3.35	0.70	0.37	0.38	1.45	11.21	13
16	U	B-T	3	1,200	1,012	282	12	113,136	M	109,596	M	3.2	1.6	93.3	1.7	3.23	50.0	3.13	1.35	11.95	6.25	8.83	2.89	17.97	34.40	16
17	U	C	2	1,200	.....	.....	12	1,997,800	M	1,946,839	M	2.6	26.2	59.2	47.8	4.23	50.5	4.19	0.38	1.69	0.43	0.81		1.24	7.50	17
846	U	P-T	2	1,200	1,000	8,760	12	1,668,900	M	1,599,147	M	4.1	25.1	61.8	38.2	4.09	39.8	4.10	0.45	2.67e	0.31	0.34	0.01	0.66	7.88	846
889	U	C-T	1	1,200	900	8,760	12	2,461,720	M	2,365,854	M	3.9	36.5	68.5	50.9	5.20	36.6	4.89	0.20	1.06	0.18	0.62	0	0.80	6.95	889
980	M	C	2	1,200	1,000	8,760	12	1,757,700	M	1,724,300	A	1.9	39.4	51.0	48.8	4.35	43.3	4.26	0.43	6.79	0.15	0.19	0.04	0.38	11.86	980
1083	U	B-T&Z	1	1,200	1,042	.....	12	2,695,050	M	2,652,550	M	1.6	38.5	73.5	51.9	4.00	47.3	3.04	0.34	1.18	0.25	0.43	0.01	0.69	5.25	1083
330	M	C	4	1,165	890	8,760	12	944,470	M	876,218	E	7.2	30.8	37.1	37.2	5.55	53.1	7.75	1.66	6.28	0.62	0.84	0	1.46	17.15	330
878	U	-T	3	1,160	977	8,760	12	2,258,880	M	1,860,122	M	17.7	36.8	75.3	44.0	3.24	50.4	3.89	0.60	1.80	0.53	0.69	0.54	1.75	8.04	878
616	M	C	3	1,150	982	8,760	12	1,581,800	E	1,430,450	M	9.6	36.1	59.0	39.6	4.40	52.9	4.20	0.59	4.75	0.45	0.73	0.23	1.41	10.96	616
887	U	C	3	1,140	938	8,760	12	1,162,920	M	1,086,909	M	6.5	39.1	36.0	48.2	4.53	47.5	5.82	0.48	5.46	1.52	0.06	0.04	1.62	13.38	887
78	I	C	2	1,060	1,000	8,760	12	2,335,124	M	2,239,317	M	4.1	31.9	54.2	69.1	5.06	48.1	5.48	0.38	3.53	0.20	0.67	0.16	1.03	10.42	78
519	M-W	C	3	1,060	890	8,760	12	1,668,238	M	1,563,450	E	6.2	48.8	57.9	46.2	3.40	42.4	3.62	0.45	2.40	0.17	2.57	0.13	2.87	9.34	519
203	M	C	2	1,050	894	8,760	12	1,586,400	M	1,460,200	M	8.0	40.3	51.1	50.4	4.16	51.3	4.49	0.90	4.11	0.17	0.02	0	0.19	9.69	203
259	M-W	C	3	1,050	870	8,760	12	810,365	M	734,445	M	9.3	44.1	52.8	24.9	5.18	57.2	5.84	0.78	7.03	0.37	0.57	0.05	0.99	14.64	259
847	U	B-T	1	1,050	900	8,760	12	2,815,400	M	2,745,800	M	2.5	45.9	63.4	71.9	4.28	38.2	3.86	0.24	1.63	0.27	0.39	0.03	0.69	6.42	847
1144	M-W	C	3	1,050	873	8,760	12	1,730,300	M	1,648,088	A	4.7	38.3	62.9	44.6	4.83	49.9	4.29	0.79	2.17	....	....	....	1.10	8.35	1144
56	I	C	2	1,000	876	2,880	12	1,351,199	M	1,251,011	E	7.4	19.3	70.3	32.7	4.96	45.0	4.43	0.35	3.27	0.30	0.14		0.44	8.49	56
801	U	B-Z	1	1,000	937	8,760	12	4,428,200	M	4,206,500	M	5.0	72.2	90.0	83.7	3.99	61.8	3.48	0.32	0.88	0.20	0.57	0.09	0.86	5.54	801
1061	U	B-Z&T	1	980	975	.....	12	2,256,400	M	2,155,929	A	4.4	36.8	83.5	46.9	3.46	26.4	3.16	0.24	0.76	0.16	1.32		1.48	5.64	1061
53	U	B-T	3	900	758	8,760	12	1,368,900	M	1,314,144	E	4.0	31.2	66.7	38.8	2.49	63.6	2.36	0.68	4.06	0.48	1.91	0.01	2.40	9.50	53
177	U	B-T	1	900	774	5,256	7.2	1,635,670	M	1,510,370	M	7.7	....	79.9	64.4	3.81	47.0	3.31	0.40	1.96	0.27	0.23	0.12	0.62	6.29	177
260	M	S&P-H	1	900	750	.....	12	180,000	M	156,190	M	13.2	3.6	48.3	7.0	3.95	60.0	4.92	0.89	2.56	0	0.35		0.35	8.72	260
560	M-W	C	3	900	746	8,760	12	709,290	M	670,266	E	5.5	25.3	39.0	34.3	2.98	55.0	4.15	0.74	6.74	0.45	0.71	0	1.16	12.79	560
848	U	P-T	2	900	750	8,760	12	1,880,400	M	1,777,476	M	5.4	41.3	63.5	56.0	5.19	41.6	6.07	1.04	2.42	0.20	1.51	0.05	1.76	11.29	848
1065	U	B-T	1	900	774	420	12	221,120	M	209,620	M	5.2	4.6	87.0	4.8	4.13	50.2	3.22	0.61	2.69	2.54	2.26	2.54	7.34	13.86	1065
189	M	C	3	850	730	8,760	12	1,010,820	M	956,138	M	5.4	38.5	32.8	61.6	3.61	75.6	4.57	0.70	6.24	0.34	0.21		0.55	12.06	189
153	U	S-	1	840	700	.....	12	81,080	M	60,200	M	25.7	1.7	....	....	4.00	66.7	4.70	1.66	25.76	6.48	11.43		17.91	50.03	153
494	U	B-T	1	840	700	.....	12	376,760	M	369,381	M	2.0	7.8	78.4	9.7	4.20	50.2	3.69	0.46	2.22	0.71	0.79	1.28	2.78	9.15	494
619	U	B-T	1	840	700	.....	12	402,770	M	390,760	M	3.0	8.2	82.3	9.9	4.28	50.1	3.34	0.66	2.59	1.01	0.52	0.28	1.81	8.40	619
855	U	P-T	1	840	700	.....	12	1,266,600	M	1,145,142	M	9.6	30.7	49.8	51.4	3.90	39.2	5.12	0.23	3.22e	0.44	1.46	0.05	1.95	10.52	855
1056	U	P-Z&T	1	840	700	.....	12	425,890	M	379,021	A	11.0	8.1	62.3	13.8	3.50	21.2	3.65	0.29	4.96	2.10	3.76		5.86	14.76	1056
731	U	P-T	1	825	750	8,760	12	478,260	M	462,470	M	3.3	9.1	68.0	14.5	5.29	48.0	5.05	1.70	8.59	1.31	0.52	1.05	2.88	18.22	731
853	U	S-T	3	810	675	2,920	12	100,000	M	87,586	M	12.4	2.1	77.4	2.7	4.36	49.1	5.82	1.27	24.48	4.95	1.70	0.94	7.59	39.16	853
648	U	B-T	2	800	666	5,000	12	1,125,370	M	1,095,200	M	2.7	32.1	67.6	35.4	3.90	46.0	3.64	0.43	2.84	0.28	0.16	0.05	0.49	7.40	648
112	M-W	C	3	740	620	8,750	12	1,193,300	M	1,104,807	M	7.5	34.1	63.1	43.4	3.78	45.1	3.94	0.69	5.28	0.25	0.31	0.05	0.61	10.52	112
1128	M	C	3	725	.....	8,760	12	619,650	M	531,546	E	14.2	27.2	46.4	31.4	4.90	50.2	5.81	0.31	6.69	0.36	0	0	0.38	13.19	1128
67	P	C	2	720	500	7,512	12	832,900	M	832,067	E	0.1	45.3	83.8	23.4	5.34	43.6	5.40	0.86	2.24	0.34	0.76	0.17	1.27	9.77	67
170	I	C	2	720	600	3,399	12	814,242	M	780,252	E	4.8	19.8	55.8	34.5	4.95	44.1	4.84	0.77	2.42	0.32	1.03		1.35	9.38	170
394	M	C	3	720	590	8,760	12	562,900	M	558,059	M	0.9	37.9	45.0	29.6	3.13	36.9	3.59	0.78	7.06	0.17	0.37	0.12	0.66	12.09	394
527	M	C	2	720	600	8,760	12	914,300	M	864,300	E	5.5	31.6	42.4	50.9	3.23	60.7	3.71	0.87	3.82	0.91	0.34	0.06	1.31	9.71	527
718	U	C	2	720	600	8,760	12	729,970	M	658,898	M	9.7	41.7	33.5	51.3	3.76	42.5	5.53	1.13	5.52	0.25	1.15	0.10	1.50	13.68	718
19	U	C	3	700	.....	.....	12	629,550	M	579,880	M	7.9	38.8	....	....	4.08	52.3	5.61	1.31	5.18	0.69	1.68		2.37	14.47	19
274	I	C	2	700	582	.....	12	2,305,000	M	2,236,000	M	3.0	61.9	70.2	79.7	4.10	46.0	4.07	0.63	1.68	0.15	0.43		0.58	6.96	274
368	I	B-H&Z	2	700	590	5,982	12	2,292,000	M	2,250,000	E	1.8	55.4	84.4	65.8	5.90	63.0	4.81	0.47	1.91	0.01	0.26	0.04	0.31	7.50	368
851	U	P-T	2	660	550	2,920	12	91,800	M	68,859	M	25.0	2.1	62.6	3.8	4.34	38.3	6.93	1.07	46.00	6.78	10.13	2.89	19.80	73.80	851
810	U	S-T	3	650	545	4,380	12	31,900	M	28,810	M	9.7	1.6	49.3	1.7	3.20	63.6	7.45	2.19	64.31	1.92	0	5.35	7.27	81.22	810
1146	M	C	3	630	511	8,760	12	495,000	M	429,120	M	13.3	28.2	41.3	32.4	4.38	51.5	5.15	1.08	7.98	3.45	0.22	0.02	3.69	17.90	1146
529	M	C	4	620	490	8,760	12	558,084	M	524,025	E	6.1	35.4	39.4	38.9	4.00	31.4	5.34	0.62	7.45	2.01	0.60	0.19	2.80	16.21	529
359	M	C	2	615	510	8,760	12	510,000	M	495,640	M	2.8	34.3	26.5	53.2	4.49	43.7	5.97	0.96	7.02	1.14	0.31	2.98	4.43	18.38	359
431	M-W	C	3	610	500	8,760	12	451,900	M	446,060	E	1.3	29.5	....	....	2.50	38.8	2.84	1.01	7.62	0.28	0.66	0.26	1.20	12.67	431
32	I	C	1	600	572	8,760	12	726,050	M	706,050	E	2.7	18.4	72.8	28.3	6.00	66.9	5.43	1.26	5.52	0.08	0.05	0	0.13	12.34	32
61	I	C	2	600	550	8,760	12	1,259,600	M	1,188,400	E	5.7	32.7	56.2	63.4	4.98	60.9	4.62	0.52	2.85	0.30	0.50	0	0.80	8.79	61
106	U	C	1	600	.....	.....	12	1,570,920	M	1,522,216	M	3.1	39.0	71.8	62.0	4.31	51.4	3.99	0.24	2.73	0.52	0.76		1.28	8.24	106
228	M-W	C	2	600	500	8,760	12	1,898,000	M	1,814,780	E	4.3	57.8	90.7	59.4	4.00	44.9	4.12	0.43	3.34	0.02	0.13	0	0.15	8.04	228
644	M-W	C	2	600	496	8,760	12	913,700	M	840,958	A	7.9	39.4	59.5	43.5	5.28	63.9	6.03	1.03	3.42	0.85	0.18	0.06	1.08	11.57	644
809	U	S-T	1	600	500	2,555	12	76,300	M	69,433	M	9.0	2.2	53.6	4.0	4.40	71.0	6.35	0.72	23.51	1.57	0	6.92	8.49	39.06	809
1094	U	B-T&Z	1	600	513	.....	12	596,800	M	583,920	M	2.2	16.6	89.4	18.9	4.18	50.1	3.43	0.34	1.39	0.60	0.71	0.24	1.55	6.71	1094
1096	U	B-T	1	600	513	2,606	12	733,520	M	716,299	M	2.3	20.4	69.8	29.8	4.20	49.9	3.40	0.33	2.40	0.62	1.06	0.16	1.84	7.97	1096
410	M	C	3	590	495	8,760	12	922,470	M	867,657	M	5.9	40.5	55.0	48.4	3.07	50.0	3.91	1.05	5.46	0.45	0.23		0.68	11.10	410
862	U	C	4	588	495	8,760	12	653,190	M	609,080	M	6.8	33.3	44.9	42.1	3.44	....	4.33	1.00	9.18	0.81	4.08	0.40	5.29	19.80	862

TABLE I—INFORMATION ON PRODUCTION COST (Page 3)

Plant Number	Character of Plant (See Notes)	Type of Load (See Notes)	Number of Engines	Total Installed B.H.P.	Total Installed K.V.A.	Total Plant Hours Operated in Reported Period	Number of Months in Reported Period	Total Gross Output—K.W. Hrs.	Determination of Gross K.W. Hrs. (See Notes)	Total Net Output—K.W. Hrs.	Determination of Net K.W. Hrs. (See Notes)	Percent of Gross K.W. Hrs. for Plant Purposes	Annual Plant Load Factor (See Text)	Running Plant Capacity Factor (See Text)	Plant Service Factor (See Text)	Average Cost of Fuel Oil—Cents per Gallon	Average Cost of Lubricating Oil—Cents per Gallon	Costs per net K.W Hr.—Mills: Fuel Oil Cost	Lubricating Oil Cost	Attendance Cost Including Superintendence	Cost of Supplies and Misc., including Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Combined Cost of All Repairs, Supplies and Miscellaneous	Total Production Cost	Plant Number
808	U	S-T	1	560	470	1,460	12	106,700	M	102,432	M	4.0	2.9	73.5	4.4	5.28	69.9	4.35	0.78	8.16	0.82	0	5.19	6.01	19.31	808
852	U	S-T	1	560	460	.....	12	174,660	M	156,631	M	10.3	6.2	67.3	7.9	5.78	34.0	5.80	0.23	1.25	5.45	0.73	0.41	6.59	13.87	852
246	M	C	3	540	430	8,760	12	412,525	M	397,000	E	3.8	29.4	33.9	38.4	5.34	57.8	7.65	1.80	7.83	0.27	0.10	0.08	0.45	17.73	246
540	M-W	C	2	540	.....	8,760	12	700,500	M	666,616	A	4.8	28.6	41.0	53.7	3.55	46.6	4.64	2.08	5.46	0.74	0.06	0.06	0.86	13.04	540
541	M-W	C	3	540	451	8,760	12	650,900	M	636,000	M	2.3	37.2	52.2	39.3	3.92	50.9	4.65	1.24	5.04	0.59	0.34	0.40	1.33	12.26	541
211	U	C	1	510	438	.....	12	1,151,190	M	1,098,749	M	4.5	39.8	....	....	4.24	51.3	3.60	0.81	2.16	0.68	1.82		2.50	9.06	211
772	U	B-T	2	500	513	780	12	107,572	M	103,495	M	3.8	3.8	73.8	5.0	4.36	51.3	4.57	1.35	6.74	5.32	3.27	1.19	9.78	22.44	772
424	M	C	2	480	400	8,159	12	665,600	M	621,800	E	6.6	34.5	47.0	50.2	3.00	49.9	3.43	1.32	4.39	0.24	0	0	0.24	9.38	424
501	M	C	3	480	380	8,760	12	417,049	M	397,167	M	4.8	35.3	36.5	40.4	4.30	51.3	6.02	1.83	11.64	0.31	1.44	0.23	1.98	21.47	501
124	M	C	3	470	385	8,760	12	515,200	E	480,890	M	6.7	39.2	42.4	43.9	4.60	42.0	5.55	1.38	7.48	0.21	0.17	0	0.38	14.79	124
315	M	C	3	460	380	8,760	12	418,900	M	408,995	M	2.4	23.7	44.2	35.0	4.70	49.1	6.79	1.28	8.80	2.29	0.71	0.14	3.14	20.01	315
471	I	B-T&Z	2	450	313	2,331	12	428,110	M	422,283	E	1.4	22.2	60.8	26.6	3.37	64.4	4.03	0.59	1.99	0.75	0.92	0	1.67	8.28	471
695	M	C	3	450	390	8,760	12	456,140	M	440,760	M	3.4	31.6	48.8	35.3	4.81	36.0	5.26	1.24	9.39	0.67	2.90	0	3.57	19.46	695
885	U	C	3	435	360	8,758	12	778,200	M	738,709	M	5.0	38.1	46.7	65.2	3.59	40.4	4.87	0.88	6.94	2.34	2.35	0.27	4.96	17.65	885
335	M-W	C	2	430	369	8,760	12	491,320	M	479,720	M	2.3	36.9	36.5	53.2	4.72	54.2	4.85	0.76	9.08	0.94	0.87	0.04	1.85	16.54	335
1209	M-W	C	2	430	375	8,760	12	515,490	M	471,690	M	8.5	38.2	40.7	50.2	4.42	55.4	6.18	0.52	6.23	0.06	0.02	0	0.08	13.01	1209
247	M-W	C	3	390	315	8,760	12	490,040	M	486,820	M	0.7	24.9	43.4	49.1	5.50	34.0	7.03	0.44	9.74	0.28	0.18	0	0.46	17.67	247
187	M-W	C	2	350	281	8,760	12	315,879	M	301,279	M	4.6	25.8	32.9	46.7	3.82	47.0	4.23	2.00	10.64	0.43	0.15	0.05	0.64	17.51	187
688	M	C	3	350	278	8,760	12	412,000	M	400,000	E	2.9	29.4	41.8	47.8	4.82	38.5	7.14	0.69	6.86	0.97	0.41	0.19	1.57	16.26	688
774	U	B-T	2	345	270	500	12	66,822	M	65,645	M	1.8	7.6	67.4	4.9	4.59	50.4	4.61	0.96	7.28	3.31	12.98	0.06	16.35	29.20	774
857	U	C	2	330	240	8,760	12	412,136	M	369,378	M	10.5	42.8	40.8	51.9	3.25	52.0	5.36	1.71	7.39	1.79	6.12	0.70	8.60	23.07	857
265	M	C	3	320	249	8,760	12	262,100	M	257,000	M	2.0	26.0	39.6	35.2	7.35	59.0	9.59	1.41	11.67	0.19	0.70	0.14	1.03	23.70	265
1055	M-W	C-Z	1	320	265	8,760	12	521,127	M	421,352	E	19.2	33.1	28.4	97.5	4.32	60.6	7.27	0.47	11.29	0.54	0	0.05	0.59	19.62	1055
27	U	C	2	315	.....	.....	12	203,800	M	186,510	M	8.5	31.0	....	....	4.14	40.0	7.29	2.13	10.88	0.77	5.16		5.93	26.23	27
737	U	C	4	305	250	8,760	12	409,926	M	314,646	M	23.2	42.5	56.3	40.6	3.96	48.7	6.02	1.73	8.09	0.94	1.14	0.44	2.52	18.36	737
382	I	C	2	300	.....	6,630	12	254,000	M	251,413	E	1.0	....	27.2	52.6	3.64	37.5	3.63	0.50	3.73	0.19	0.02	0	0.21	8.07	382
858	U	C	2	270	215	8,760	12	211,600	M	172,400	M	18.5	39.6	26.7	49.6	3.12	46.4	7.17	3.13	16.40	3.81	6.85	1.00	11.66	38.36	858
169	I	C	1	240	200	1,809	12	84,090	M	79,570	E	5.4	6.0	28.8	20.7	4.50	50.8	6.34	1.13	4.52	0.98	8.74		9.72	21.71	169
677	I	C	1	240	200	.....	12	235,000	E	210,000	M	10.6	19.9	74.1	22.5	4.61	41.7	3.95	1.19	1.43	0.36	0.95	0	1.31	7.88	677
591	U	B-T	1	225	200	8,760	12	329,143	M	317,143	M	3.6	23.5	66.8	37.3	3.43	50.1	3.99	0.93	3.60	0.16	0.23	0.21	0.60	9.12	591
984	U	S-	1	225	219	2,160	12	29,000	M	26,851	E	7.4	1.8	48.5	4.5	4.29	45.7	5.07	0.60	5.59	0.75	0.82	0.19	1.76	13.02	984
318	M	C	4	212½	143	8,760	12	144,230	M	139,730	E	2.9	26.6	....	...	3.69	53.2	6.81	2.37	13.43	2.00	0.34	1.20	3.54	26.15	318
1193	M-W	C	1	200	170	8,760	12	424,400	M	408,307	A	3.8	42.1	64.0	56.5	5.00	42.9	6.24	0.64	2.74	.....	0.26	....	0.97	10.59	1193
733	U	S-T	2	175	135	68	12	2,135	M	1,892	M	11.4	0.2	53.2	0.4	6.03	50.0	16.00	3.17	38.34	20.20	0	37.20	57.40	114.91	733
646	M	S-H	1	120	90	8,736	12	8,990	M	8,074	M	10.2	....	11.1	11.4	5.39	55.5	14.62	4.34	21.92	12.87	9.91	8.55	31.33	72.21	646
1201	M	C	2	100	78	8,760	12	58,550	M	45,350	E	22.6	29.1	....	....	6.36	65.4	15.52	6.22	39.85	3.60	0.18	0	3.78	65.37	1201

NOTES—Character of Plant
U—Private Power Company
P—Private Pumping Company
M—Municipal Power Plant
W—Municipal Pumping Plant
I—Industrial Power Plant
B—City Building Power Plant

Determination of Output
M—Metered
E—Estimated from Gross (or Net)
A—Metered Plant Consumption Subtracted from Gross (or Added to Net)

Type of Load
C—Complete Power
B—Base Load
S—Stand by
P—Peak Load
V—Type Varied during Period
—T—Supplemented by Transmission Line
—H—Supplemented by Hydro-Electric Units
—Z—Supplemented by Steam Units
—G—Supplemented by Gas Engines

Lettered Notes
a—Attendance Cost includes no Repair Labor; Repair Costs include All Repair Labor.
b—Steam Plant used in Emergencies Only.
c—No Cost included for Water, which goes to House Supply.
d—K.W. Rating; Direct Current.
e—No Deduction made for Attendance of Ice Plant.
f—Does not include $1,885 for Cast Iron Piston Heads to Replace Steel; Change made for Operating Reasons and Charged to Capital Account.
g—No Deduction made for Attendance of Water Pumping Plant.

TABLE II—COMPARATIVE COSTS—1929, 1930, 1931, 1932 AND 1933 REPORTS (Page 1)

Year	Total B.H.P. Installed	Total Net Output K.W. Hrs.	Annual Plant Load Factor	Running Plant Capacity Factor	Plant Service Factor	Aver. Cost Fuel Oil—Cents per Gallon	Costs per Net K.W. Hr.—Mills: Fuel Cost	Lub. Oil Cost	Atten. Cost, Incl. Superint.	Cost Supplies & Misc., Incl. Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Total All Supply Repair & Misc. Costs	Total Production Cost	Year	Plant No.
1929	11,540	22,591,027	.....	69.9	....	4.25	3.82	0.69	0.60	.....	.....	.....	1.04	6.15	1929	43
1930	11,540	26,221,176	46.1	70.4	57.8	4.37	3.95	0.53	0.94	0.21	0.67	0.05	0.93	6.35	1930	
1931	11,540	29,849,848	52.5	73.2	65.7	3.78	3.51	0.47	0.70	0.28	0.63	0.29	1.20	5.88	1931	
1932	15,640	28,374,009	57.1	83.3	46.0	3.48	3.23	0.31	0.86	0.30	0.56	0.14	1.00	5.40	1932	
1933	15,640	27,434,541	55.1	74.3	45.1	3.39	2.88	0.23	0.77	0.09	0.75	0.23	1.07	4.95	1933	
1930	5,660	7,958,851	31.3	65.0	35.9	5.71	5.22	0.52	3.73	1.38	1.91	1.[illegible]8	4.37	13.86	1930	82
1931	5,660	8,778,880	33.2	69.0	39.1	5.13	4.93	0.45	2.94	0.92	1.96	1.22	4.10	12.42	1931	
1932	8,960	9,065,633	33.0	60.3	40.5	4.48	4.52	0.63	2.81	0.47	1.13	1.57	3.17	11.13	1932	
1933	8,960	9,014,095	34.0	63.2	30.0	4.24	3.94	0.47	2.74	0.87	1.37	1.45	3.69	10.84	1933	
1929	3,330	5,722,032	31.1	65.3	45.2	5.58	5.38	0.55	3.83	0.88	0.74	0.40	2.02	11.78	1929	52
1930	4,580	7,257,703	33.5	75.2	45.4	5.70	5.30	0.38	2.83	0.74	0.56	0.48	1.78	10.29	1930	
1931	4,580	8,417,102	33.7	78.6	40.4	4.83	4.46	0.30	2.55	0.63	0.49	0.38	1.50	8.81	1931	
1932	7,445	9,110,000	36.3	78.1	43.8	4.41	3.97	0.27	2.35	0.52	0.35	0.14	1.01	7.60	1932	
1933	7,445	9,530,892	37.6	78.3	29.0	4.26	3.75	0.24	2.43	0.21	0.48	0.09	0.78	7.20	1933	
1930	5,000	8,016,000	37.9	64.0	44.4	1.30	1.34	0.31	2.62	0.01	0.10	0.01	0.12	4.39	1930	73
1931	5,000	8,341,500	41.9	66.3	45.1	0.95	0.93	0.26	1.93	0.13	0.22	0.05	0.40	3.52	1931	
1932	5,000	8,030,200	42.0	66.4	43.4	1.22	1.26	0.29	2.01	0.16	0.16	0.02	0.34	3.90	1932	
1933	5,000	8,379,100	44.3	67.2	45.1	1.60	1.69	0.32	2.03	0.08	0.33	0.02	0.43	4.47	1933	
1929	4,250	7,442,350	36.8	72.5	43.6	5.23	5.04	0.09	1.65	0.06	....	....	0.92	7.70	1929	45
1930	4,250	6,908,500	34.9	69.5	42.4	5.29	5.18	0.09	1.77	0.04	1.01	0.10	1.15	8.20	1930	
1931	4,250	5,537,000	46.4	66.5	36.6	4.79	4.89	0.09	2.04	0.07	1.28	0.55	1.90	8.92	1931	
1932	4,250	5,015,575	42.3	62.1	35.8	3.87	4.07	0.11	2.05	0.05	1.33	0.32	1.70	7.93	1932	
1933	4,250	4,471,550	35.6	56.9	35.1	3.10	3.30	0.16	2.56	0.07	0.39	0.15	0.61	6.63	1933	
1932	2,475	4,105,401	37.6	....	....	3.23	3.03	0.49	3.88	0.31	0.24	0.48	1.03	8.43	1932	111
1933	3,675	4,543,778	39.1	63.2	37.6	3.45	3.29	0.41	3.27	0.44	0.25	0.35	1.04	8.01	1933	
1930	3,600	4,484,700	41.8	54.1	50.7	4.72	4.59	0.89	1.36	0.77	0.82	0.17	1.76	8.60	1930	130
1931	3,600	4,168,750	42.4	67.0	31.4	4.19	3.93	0.56	1.58	0.71	1.96	0.18	2.85	8.92	1931	
1932	3,600	4,281,230	44.7	68.6	31.3	4.02	3.83	0.66	1.65	0.47	0.68	0.19	1.34	7.48	1932	
1933	3,600	4,919,360	43.7	67.8	36.5	4.27	4.27	0.69	1.50	0.43	0.37	0.10	0.90	7.36	1933	
1932	3,520	4,378,509	19.8	82.3	26.0	4.16	3.88	0.24	0.80	0.24	0.58	0.05	0.87	5.79	1932	157
1933	3,520	2,122,944	10.7	83.6	12.5	4.48	4.07	0.31	1.56	0.32	0.32	0.02	0.66	6.60	1933	
1929	3,450	16,479,500	83.2	94.4	84.5	2.71	2.62	0.33	1.40	0.13	....	....	0.47	4.82	1929	2
1930	3,450	16,077,095	78.8	94.3	77.1	2.18	1.98	0.45	1.14	0.09	1.56	0.09	1.74	5.31	1930	
1931	3,450	17,745,325	86.5	97.8	89.8	2.11	2.00	0.26	1.09	0.08	1.16	0.09	1.33	4.68	1931	
1932*a*	3,450	8,839,511	....	97.8	91.2	2.33	2.22	0.24	1.03	0.10	1.11	0.08	1.29	4.78	1932*a*	
1933	3,450	4,980,440	24.6	97.3	25.7	1.92	1.77	0.15	1.82	0.11	0.36	0.04	0.51	4.24	1933	
1930	3,360	14,709,450	81.4	90.7	72.7	3.66	2.91	0.31	1.38	0.16	1.12	0.19	1.47	6.07	1930	164
1931	3,360	11,037,481	59.5	76.3	76.9	3.34	2.66	0.28	1.73	0.35	1.52	0.30	2.17	6.84	1931	
1932	3,360	12,838,281	....	80.0	84.9	2.59	2.12	0.27	1.28	0.55	1.37	0.46	2.38	6.05	1932	
1933	3,360	13,289,000	....	87.0	80.1	4.01	3.15	0.29	1.32	0.24	1.80	0.60	2.64	7.41	1933	
1932	3,000	3,978,113	34.9	42.8	68.9	4.52	4.25	0.54	2.10	0.48	....	....	0.97	7.86	1932	77
1933	3,000	4,511,158	38.9	39.3	83.5	4.91	4.67	0.48	1.87	0.35	0.83	0.01	1.19	8.21	1933	
1930*b*	1,800	885,399	....	48.1	16.3	5.53	6.33	1.26	3.78	0.88	0.60	0.11	1.59	12.96	1930*b*	109
1931	2,925	1,858,860	....	54.1	30.3	5.60	6.29	1.25	2.32	0.27	0.80	0	1.07	10.93	1931	
1932	2,925	959,606	8.9	49.2	11.5	5.69	6.85	0.64	5.01	0.24	0.75	0.10	1.09	13.59	1932	
1933	2,925	931,425	9.5	47.9	11.7	5.95	7.51	0.73	6.85	0.90	0.80	0.10	1.80	16.89	1933	
1929	1,830	3,231,938	36.0	64.8	53.2	5.77	5.31	0.36	3.06	1.34	....	....	3.98	12.71	1929	7
1930	2,730	3,211,821	38.0	61.8	53.1	4.79	4.52	0.35	3.17	1.19	1.57	0.31	3.07	11.11	1930	
1931	2,730	3,088,885	43.9	57.3	36.4	3.43	3.08	0.39	3.79	0.68	1.28	0.51	2.47	9.73	1931	
1932	2,730	3,105,742	42.5	57.9	36.3	3.27	2.78	0.25	3.29	0.42	0.96	0.39	1.77	8.09	1932	
1933	2,730	3,114,320	41.6	57.5	36.4	3.80	3.48	0.27	3.04	0.35	0.72	0.58	1.65	8.44	1933	
1930	2,520	4,848,480	37.4	59.7	61.1	3.65	3.73	0.91	1.61	....	....	....	2.08	8.33	1930	732
1931	2,520	2,632,385	25.0	49.1	44.1	2.82	3.68	1.14	2.19	0.59	1.33	0.77	2.69	9.70	1931	
1932	2,520	3,497,637	27.5	50.4	47.4	3.17	3.27	0.73	2.09	0.57	2.48	0.37	3.42	9.51	1932	
1933	2,520	988,290	10.0	52.0	15.8	2.62	3.99	1.25	8.32	1.55	2.82	0.35	4.72	18.28	1933	
1931	2,520	2,247,295	....	....	....	3.33	3.11	0.47	1.23	0.42	....	....	0.71	5.52	1931	978
1932	2,520	2,223,852	14.4	87.6	17.5	3.57	3.11	0.27	1.41	0.35	....	....	0.74	5.53	1932	
1933	2,520	142,039	1.9	....	....	3.97	4.00	0.47	18.09	4.04	....	....	9.78	32.34	1933	
1930	2,400	1,658,900	24.1	37.0	33.7	4.62	5.54	0.94	4.81	....	....	....	3.24	14.53	1930	60
1931	2,400	No reply to inquiries for 1931.													1931	
1932	2,400	1,015,200	13.7	24.8	32.3	4.69	7.48	0.73	5.22	0.60	....	....	2.76	16.19	1932	
1933	2,400	777,920	20.6	21.6	30.8	5.16	9.83	1.52	11.34	0.25	....	....	1.21	23.90	1933	
1932*c*	2,400	592,781	....	....	....	3.68	3.19	0.22	1.99	0.57	....	....	0.60	6.00	1932*c*	1149
1933	2,400	262,329	2.0	....	....	3.90	3.68	0.21	11.44	2.00	....	....	2.81	18.14	1933	
1929	2,370	3,798,810	39.6	....	....	5.51	5.43	0.48	4.11	0.24	0.22	0.07	0.53	10.55	1929	41
1930	2,370	4,068,290	39.2	59.0	44.2	5.19	5.09	0.48	4.08	0.37	0.63	0.15	1.15	10.80	1930	
1931	2,370	4,092,730	39.4	67.3	44.2	4.57	4.48	0.51	3.85	0.25	0.24	0.13	0.62	9.46	1931	
1932	2,370	3,698,090	35.6	65.5	41.0	4.10	3.86	0.62	4.05	0.23	0.26	0.08	0.57	9.10	1932	
1933	2,370	3,279,790	31.7	59.7	40.0	4.37	4.45	0.66	4.44	0.39	0.17	0.39	0.95	10.50	1933	
1930	1,320	1,270,520	19.7	68.0	26.3	5.62	6.46	1.15	4.01	0.39	2.37	0.97	3.73	15.35	1930	723
1931	2,370	1,556,510	....	73.3	....	4.21	4.23	0.95	3.56	0.53	0.86	0.70	2.09	10.83	1931	
1932	2,370	1,371,480	10.9	67.2	15.4	4.31	4.13	0.74	3.71	0.76	....	....	2.55	11.13	1932	
1933	2,370	1,349,830	10.2	73.8	13.7	4.41	4.24	0.53	4.59	0.72	1.11	0.28	2.11	11.47	1933	
1930	2,170	3,184,025	42.6	67.3	38.8	3.33	3.12	0.46	4.13	0.08	0.49	0.31	0.88	8.59	1930	79
1931	2,170	3,204,390	38.6	66.8	39.6	2.62	2.38	0.30	3.31	0.13	0.20	0.13	0.46	6.45	1931	
1932	2,170	3,280,357	39.3	66.4	40.6	2.49	2.21	0.45	3.53	0.11	0.23	0	0.34	6.53	1932	
1933	2,170	3,065,966	41.0	64.8	39.1	3.23	2.88	0.52	3.12	0.43	0.39	0	0.82	7.34	1933	
1929	2,160	319,120	3.7	....	....	4.15	5.45	1.77	11.61	3.56	....	....	17.99	36.82	1929	5
1930	2,160	1,013,269	8.1	....	....	4.04	4.86	1.25	5.56	1.14	....	....	8.17	19.84	1930	
1931	2,160	1,789,653	10.0	....	....	3.33	3.86	0.80	2.15	0.79	....	....	2.18	8.99	1931	
1932	2,160	2,597,100	21.5	94.4	22.6	3.54	3.90	0.65	1.31	0.53	....	....	1.39	7.25	1932	
1933	2,160	834,039	7.0	....	....	4.02	4.59	0.54	3.65	0.45	....	....	1.10	9.89	1933	

TABLE II—COMPARATIVE COSTS—1929, 1930, 1931, 1932 AND 1933 REPORTS (Page 2)

Plant No.	Year	Total Installed B.H.P.	Total Net Output K.W. Hrs.	Annual Plant Load Factor	Running Plant Capacity Factor	Plant Service Factor	Aver. Cost Fuel Oil—Cents per Gallon	Costs per Net K. W. Hr.—Mills								Year
								Fuel Cost	Lub. Oil Cost	Atten. Cost, Incl. Superint.	Cost Supplies & Misc., Incl. Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Total All Supply Repair & Misc. Costs	Total Production Cost	
6	1929	2,100	1,318,898	10.0	....	....	4.70	4.17	0.72	2.67	0.47	...	...	1.61	9.17	1929
	1930	2,100	1,576,234	18.8	....	....	4.51	3.93	0.57	2.07	0.40	....	...	2.03	8.60	1930
	1931	2,100	1,612,957	11.8	....	....	4.12	3.53	0.62	1.89	0.31	....	...	1.13	7.17	1931
	1932	2,100	1,720,413	11.7	97.4	14.5	3.94	3.40	0.45	1.64	0.25	....	...	1.05	6.54	1932
	1933	2,100	1,616,773	12.7	93.5	14.3	4.34	3.79	0.43	1.67	0.32	....	....	1.15	7.04	1933
68	1931	2,060	3,336,860	59.4	67.5	42.7	3.37	3.30	0.44	1.41	0.11	0.31	0.37	0.79	5.94	1931
	1932	2,060	3,038,210	54.8	63.9	40.9	3.60	3.60	0.42	1.54	0.18	0.43	0.08	0.69	6.25	1932
	1933	2,060	3,347,210	59.9	65.4	44.4	3.73	4.02	0.50	1.29	0.13	0.46	0.04	0.63	6.44	1933
215	1930*d*	1,960	1,372,941	....	78.5	17.5	5.40	4.68	0.58	1.12	0.33	0.01	0.10	0.44	6.82	1930*d*
	1931	1,960	1,568,700	13.1	89.9	15.5	3.97	3.45	0.21	1.40	0.38	0.53	0.08	0.99	6.05	1931
	1932	1,960	1,163,370	9.8	84.2	12.3	5.14	3.84	0.29	1.48	0.55	0.07	0	0.62	6.23	1932
	1933	1,960	1,163,860	11.4	78.9	13.1	4.49	4.02	0.32	1.44	0.55	0.46	0	1.01	6.79	1933
837	1930	1,875	2,016,465	33.2	49.0	38.8	3.07	3.80	0.68	7.39	0.66	3.32	1.12	5.10	16.97	1930
	1931	1,875	2,101,374	35.9	51.1	40.2	2.72	3.43	0.65	6.01	0.49	3.36	0.92	4.77	14.86	1931
	1932	1,875	2,057,699	37.9	48.9	41.2	2.49	3.29	0.80	5.89	0.48	6.63	0.90	8.01	17.99	1932
	1933	1,875	1,920,591	39.3	47.1	39.8	2.51	3.57	0.90	6.01	0.51	5.15	0.98	6.64	17.12	1933
1033	1932	1,865	480,770	6.2	64.8	7.1	3.42	3.73	0.58	10.33	4.05	6.44	1.18	11.67	26.31	1932
	1933	1,865	186,791	2.8	64.1	2.9	4.17	5.31	0.80	21.35	3.76	3.17	3.87	10.80	38.26	1933
421	1932	800	2,485,908	57.1	69.6	80.2	2.20	2.04	0.18	4.23	0	0	0	0	6.45	1932
	1933	1,800	3,689,473	....	63.1	....	2.32	2.02	0.47	2.85	0.16	0.07	0	0.23	5.57	1933
158	1932	1,760	512,498	6.0	32.7	17.0	5.87	8.69	1.06	3.00	2.62	1.09	0.77	4.48	17.23	1932
	1933	1,760	317,690	3.9	55.4	6.0	6.06	7.24	0.56	5.35	4.90	0.07	0.39	5.36	18.51	1933
212	1931	1,750	228,700	3.6	69.6	3.2	4.43	4.13	0.51	2.21	0.28	0.09	0	0.37	7.22	1931
	1932	1,750	217,147	4.4	71.8	2.9	3.60	3.22	0.30	2.14	0.29	6.40	0	6.69	12.35	1932
	1933	1,750	336,189	6.8	70.8	4.6	3.60	3.27	0.29	2.17	0.30	2.07	0	2.37	8.10	1933
722	1930	1,705	796,450	9.3	82.1	11.2	5.61	5.97	0.69	7.99	1.49	1.19	0.90	3.58	18.23	1930
	1931	1,705	826,340	10.1	72.8	13.2	4.26	4.63	0.56	8.48	1.03	0.14	0.44	1.61	15.28	1931
	1932	1,705	896,220	10.0	62.4	15.7	4.68	5.07	0.63	6.53	0.94	....	....	2.55	14.78	1932
	1933	1,705	709,180	8.0	84.9	9.1	4.53	4.36	0.56	7.98	1.25	1.26	0.32	2.83	15.73	1933
18	1929	1,650	2,351,123	26.4	....	...	4.71	4.52	0.41	2.58	0.38	....	....	2.30	9.81	1929
	1930	1,650	2,406,690	27.2	....	.	4.49	4.51	0.61	2.08	0.21	....	....	4.80	12.00	1930
	1931	1,650	2,406,609	26.0	....	...	3.94	3.93	0.58	1.98	0.41	....	....	2.24	8.73	1931
	1932	1,650	2,327,071	26.3	62.4	40.0	3.74	3.78	0.51	1.72	0.34	....	....	1.44	7.45	1932
	1933	1,650	2,112,805	26.8	60.4	37.6	4.22	4.16	0.50	1.74	0.31	....	....	1.03	7.44	1933
88	1932	1,620	2,497,042	41.2	58.6	....	2.31	2.39	0.47	2.86	0.36	0.10	0	0.46	6.18	1932
	1933	1,620	2,470,900	42.8	57.9	45.9	3.04	3.18	0.48	2.84	0.36	0.10	0	0.46	6.96	1933
8	1930	1,560	2,049,000	34.2	57.0	39.1	3.37	3.40	0.58	4.68	0.70	0.27	0	0.97	9.63	1930
	1931	1,560	1,876,410	33.4	58.7	35.3	2.81	2.92	0.41	3.61	....	....	....	0.54	7.48	1931
	1932	1,560	1,627,980	31.4	55.0	32.7	3.04	3.26	0.54	4.85	....	....	....	0.62	9.27	1932
	1933	1,560	1,511,411	....	51.6	32.8	3.44	3.64	0.43	4.84	0.26	.07	0.08	1.41	10.32	1933
10	1929	1,500	3,154,085	91.2	74.7	48.9	2.97	3.00	0.97	3.28	0.19	....	....	0.46	7.71	1929
	1930	1,500	3,058,452	....	72.1	48.5	2.42	2.33	0.78	3.09	0.07	0.78	0.42	1.27	7.47	1930
	1931	1,500	3,000,700	78.5	69.9	49.0	2.45	2.27	0.66	5.38	0.13	0.84	0.52	1.49	9.80	1931
	1932	1,500	Intermittent Operation in 1932; Records Incomplete.													1932
	1933	1,500	2,057,220	54.0	66.6	35.4	1.82	1.68	0.25	3.72	0.47	0.74	1.07	2.28	7.92	1933
1154	1932	1,500	2,044,267	36.3	46.5	50.5	5.84	6.07	0.70	7.04	1.17	0.07	0.39	1.63	15.44	1932
	1933	1,500	2,433,000	37.4	54.3	51.2	5.51	5.47	0.22	6.16	0.23	0.12	0.05	0.40	12.25	1933
289	1931	1,465	2,523,740	38.4	71.3	42.7	4.15	3.67	0.51	4.71	0.32	....	....	1.44	10.33	1931
	1932	1,465	2,528,017	36.5	71.1	43.9	4.17	3.78	0.43	4.60	0.32	0.12	1.13	1.57	10.38	1932
	1933	1,465	2,625,010	38.3	71.0	44.9	4.30	3.83	0.62	4.29	0.33	0.54	0.26	1.13	9.87	1933
496	1932	1,450	1,101,905	21.1	45.5	31.1	4.02	4.32	0.34	5.48	0.52	0.51	0.42	1.45	11.59	1932
	1933	1,450	1,108,150	21.1	44.4	31.7	4.08	4.39	0.37	4.98	0.89	0.44	0	1.33	11.07	1933
70	1930	1,420	1,980,400	....	....	....	3.68	3.81	0.44	3.84	0.13	0.12	0.05	0.30	8.39	1930
	1931	1,420	1,868,725	41.7	62.0	39.4	2.83	3.25	0.46	3.48	0.32	0.85	0.38	1.55	8.74	1931
	1932	1,420	1,675,057	38.4	54.3	41.5	3.03	3.71	0.53	4.25	0.27	0.53	0	0.80	9.29	1932
	1933	1,420	1,594,598	41.7	52.0	41.2	3.16	3.92	0.61	3.20	0.24	0.08	1.21	1.53	9.26	1933
154	1930	1,400	1,571,594	26.8	....	..	4.48	3.79	0.32	3.95	0.35	..	...	0.71	8.77	1930
	1931	1,400	1,608,939	29.3	....	..	3.59	2.94	0.22	4.22	0.44	.	.	1.58	8.96	1931
	1932	1,400	1,521,613	29.4	81.9	23.0	3.47	2.81	0.29	4.18	0.33	....	.	0.81	8.09	1932
	1933	1,400	1,483,854	30.3	79.2	23.2	3.87	3.18	0.33	2.81	0.31	...	.	1.79	8.11	1933
163	1930	1,400	5,125,835	60.4	71.4	82.1	2.44	2.13	0.21	1.12	0.29	....	. .	3.44	6.90	1930
	1931	1,400	3,793,300	43.6	76.3	63.7	1.92	1.75	0.16	1.60	0.21	.	.	2.16	5.67	1931
	1932	1,400	127,335	1.7	50.4	3.4	0.97	1.21	0.36	7.30	0.36	5.53	0.58	6.47	15.34	1932
	1933	1,400	1,636,205	20.2	55.0	39.1	3.44	3.58	0.17	1.24	0.74	....	....	2.81	7.80	1933
198	1932*e*	1,400	2,089,869	....	83.6	56.7	3.63	3.31	0.34	0.42	0.06	0.12	0.05	0.23	4.30	1932*e*
	1933	1,400	3,514,032	41.9	70.6	63.1	3.52	3.26	0.11	0.77	0.11	....	....	0.53	4.67	1933
517	1932	1,375	1,050,715	30.7	27.9	50.1	3.74	4.48	0.61	4.84	0.25	0.05	0.40	0.70	10.63	1932
	1933	1,375	1,034,979	34.2	27.7	50.1	3.65	4.51	0.76	4.19	0.30	0.07	0.01	0.38	9.84	1933
888	1932	1,375	2,168,250	31.0	49.8	55.4	4.02	4.21	0.35	5.19	1.43	1.35	0.76	3.54	13.29	1932
	1933	1,375	2,252,600	31.6	52.1	55.2	4.69	4.76	0.32	5.45	2.02	2.52	0.68	5.22	15.75	1933
725	1930	1,310	1,976,000			..	4.40	4.39	0.84	2.58	0.38	0.46	0.20	1.04	8.85	1930
	1931	1,310	2,640,671	...	....	..	3.35	3.16	0.58	1.78	0.40	0.21	0.15	0.76	6.28	1931
	1932	1,310	3,324,653	59.8	74.4	63.8	3.62	3.43	0.81	1.70	0.18	0.24	0.02	0.44	6.38	1932
	1933	1,310	2,013,550	37.5	57.8	46.5	3.59	3.38	0.80	2.19	0.32	0.04	0.02	0.38	6.75	1933
886	1932	1,305	889,868	28.5	39.3	31.4	4.74	7.00	1.39	5.20	1.68	0.89	0.15	2.72	16.31	1932
	1933	1,305	865,747	34.0	40.7	29.3	4.74	7.00	1.26	5.88	1.71	2.76	0.13	4.60	18.74	1933

TABLE II—COMPARATIVE COSTS—1929, 1930, 1931, 1932 AND 1933 REPORTS (Page 3)

Year	Total Installed B.H.P.	Total Net Output K.W. Hrs.	Annual Plant Load Factor	Running Plant Capacity Factor	Plant Service Factor	Aver. Cost Fuel Oil—Cents per Gallon	Costs per Net K. W. Hr.—Mills								Year	Plant No.
							Fuel Cost	Lub. Oil Cost	Atten. Cost, Incl. Superint.	Cost Supplies & Misc., Incl. Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Total All Supply Repair & Misc. Costs	Total Production Cost		
1929	1,225	1,169,971	33.8	55.9	34.1	6.00	7.44	0.57	4.74	1.00	0.89	0.77	2.66	15.41	1929	13
1930	1,225	1,131,661	32 7	59.2	31.2	5.69	6.60	0.65	4.88	0.54	0.39	0.08	1.01	13.14	1930	
1931	1,225	1,259,958	38.4	58.3	34.1	5.41	6.29	0.73	4.69	0.24	0.31	0.05	0.60	12.31	1931	
1932	1,225	1,176,048	36 0	57.4	32.4	5.13	5.94	0.68	4.50	0.48	0.59	0.37	1.44	12.56	1932	
1933	1,225	1,153,244	39.6	56.4	32.0	4.72	5.55	0.86	3.35	0.70	0.37	0.38	1.45	11.21	1933	
1932	1,200	379,610	5.5	98.2	5.6	3.69	3.43	0.54	3.82	2.04	0.65	0.87	3.56	11.35	1932	16
1933	1,200	109,596	1.6	93.3	1.7	3.23	3.13	1.35	11.95	6.25	8.83	2.89	17.97	34.40	1933	
1929	1,200	1,611,876	20.7	....	....	4.52	4.69	0.53	2.64	0.67	....	....	2.11	9.97	1929	17
1930	1,200	2,148,910	27.5	....	....	4.45	4.23	0.50	2.06	0.36	....	....	1.96	8.75	1930	
1931	1,200	2,207,300	27.2	....	....	3.97	3.83	0.40	1.82	0.42	....	....	1.89	7.94	1931	
1932	1,200	2,064,882	24.1	58.3	51.4	3.71	3.67	0.38	1.66	0.38	....	....	1.36	7.07	1932	
1933	1,200	1,946,839	26.2	59.2	47.8	4.23	4.19	0.38	1.69	0.43	....	....	1.24	7.50	1933	
1931	1,200	2,143,170	38.5	....	....	5.32	5.06	0.46	4.39	0.44	0.56	0	1.00	10.91	1931	980
1932	1,200	No Reply to	Inquiries for 1932.												1932	
1933	1,200	1,724,300	39.4	51.0	48.8	4.35	4.26	0.43	6.79	0.15	0.19	.04	0.38	11.86	1933	
1932	1,200	2,144,290	24.9	70.5	43.8	3.58	2.81	0.41	1.04	0.26	0.15	0.08	0.49	4.75	1932	1083
1933	1,200	2,652,550	38.5	73.5	51.9	4.00	3.04	0.34	1.18	0.25	0.43	0.01	0.69	5.25	1933	
1932	1,160	1,878,245	32.3	74.6	43.9	2.71	3.44	0.70	2.39	0.63	0.50	0.60	1.73	8.26	1932	878
1933	1,160	1,860,122	36.8	75.3	44.0	3.24	3.89	0.60	1.80	0.53	0.69	0.54	1.75	8.04	1933	
1930	1,150	1,553,500	37.2	....	....	5.10	4.83	0.85	4.81	....	....	....	0.39	10.88	1930	616
1931	1,150	1,609,550	38.8	....	....	4.50	4.35	0.76	4.32	....	2.48	...	2.79	12.22	1931	
1932	1,150	1,565,000	39.0	56.5	44.7	4.51	4.31	0.64	4.04	1.06	1.97	0	3.03	12 02	1932	
1933	1,150	1,430,450	36.1	59.0	39.6	4.40	4.20	0.59	4.75	0.45	0.73	0.23	1.41	10.96	1933	
1932	1,140	1,102,053	42.5	45.9	38.7	4.16	5.26	0.99	5.25	1.74	0.06	0.09	1.89	13 39	1932	887
1933	1,140	1,086,909	39.1	36.0	48.2	4.53	5.82	0.48	5.46	1.52	0.06	0.04	1.62	13.38	1933	
1928/30*f*	1,060	4,867,305	....	55 5	88.7	5.08	4.92	0.82	2.79	0 08	0.61	0.13	0.82	9.35	1928/30*f*	78
1931	1,060	1,906,347	31.4	46.5	69.2	5.07	5.88	1.13	4.69	0.23	0.15	0.19	0.57	12.27	1931	
1932*g*	1,060	1,507,615	....	44.4	59.8	5.15	6.23	0.38	4.50	0.49	....	....	1.00	12.11	1932*g*	
1933	1,060	2,239,317	31.9	54.2	69.1	5.06	5.48	0.38	3.53	0.20	0.67	0.16	1.03	10.42	1933	
1932	1,060	1,561,470	47.2	....	....	5.42	4.58	0.70	3.08	....	....	....	3.75	12.11	1932	519
1933	1,060	1,563,450	48.8	57.9	46.2	3.40	3.62	0.45	2.40	0.17	2.57	0.13	2.87	9.34	1933	
1932*h*	1,050	1,464,600	42.0	55.7	45.0	3.37	3.81	0.95	4.56	0.72	0	0	0.72	10.04	1932*h*	203
1933	1,050	1,460,200	40.3	51.1	50.4	4.16	4.49	0.90	4.11	0.17	0.02	0	0.19	9.69	1933	
1932	1,050	725,222	41.4	49.5	26.1	5.08	5.77	0.91	7.30	0.43	0.02	0	0.45	14.43	1932	259
1933	1,050	734,445	44.1	52.8	24.9	5.18	5.84	0.78	7.03	0.37	0.57	0.05	0.99	14.64	1933	
1932	1,050	1,534,790	36.4	62.6	40.9	4.87	4.12	0.77	2.03	.. .	...	....	0.88	7.80	1932	1144
1933	1,050	1,648,088	38.3	62.9	44.6	4.83	4.29	0.79	2.17	..	....	...	1.10	8.35	1933	
1930	1,000	4,110,052	74.3	74.6	94.9	3.82	4.19	0.43	1.25	0.79	0.89	0.17	1.85	7.72	1930	801
1931	1,000	4,616,205	78.0	84.9	95.8	3.31	3.28	0.30	1.04	1.20	0.28	0.02	1.50	6.12	1931	
1932	1,000	4,524,387	78.7	85.2	96.2	3.20	3.36	0.27	1.04	0.14	0.30	0.06	0 50	5.17	1932	
1933	1,000	4,206,500	72.2	90.0	83.7	3.99	3.48	0.32	0.88	0.20	0.57	0.09	0.86	5.54	1933	
1930	980	1,405,473	....	96.7	49.4	4.32	3.22	0.56	0.68	0.10	....	....	0.55	5.01	1930	1061
1931	980	1,974,459	33.4	81.4	43.7	3.98	3.59	0.56	0.92	0.18	0.63	0 10	0.91	5.98	1931	
1932	980	2,974,884	50.1	94.5	56.4	3.25	2.95	0.36	0.61	0.14	0.59	0.25	0.98	4.90	1932	
1933	980	2,155,929	36.8	83.5	46.9	3.46	3.16	0.24	0.76	0.16	....	....	1.48	5.64	1933	
1930	900	2,300,000	50.4	70.6	63.7	3.26	3.68	0.73	2.12	0.43	1.76	0.05	2.24	8.77	1930	53
1931	900	2,355,470	52.8	71.0	65.2	2.65	3.06	0 53	2.00	0.42	2.94	0.05	3 41	9.00	1931	
1932	900	1,975,660	44.2	69.0	56.2	2.55	2.90	0 41	2.21	0.41	3.79	0.02	4 22	9.74	1932	
1933	900	1,314,144	31.2	66.7	38.8	2.49	2.36	0.68	4.06	0.48	1.91	0.01	2.40	9.50	1933	
1931	900	38,740	1.5	50.6	3.0	5.00	11.17	0.65	6.24	4.44	0	0	4.44	22.50	1931	260
1932	900	68,389	1.7	47.0	3.6	3.39	5.34	1.42	5.26	0	0.18	0	0.18	12 20	1932	
1933	900	156,190	3.6	48.3	7.0	3.95	4.92	0.89	2.56	0	....	....	0.35	8.72	1933	
1932	900	363,000	8.7	83.3	8.6	3 81	3 22	0.66	1.65	1.82	1.04	1 25	4.11	9 64	1932	1065
1933	900	209,620	4.6	87.0	4.8	4.13	3.22	0.61	2.69	2.54	2.26	2.54	7.34	13.86	1933	
1930	850	800,000	32.4	27.4	59.5	4 10	5.22	0.93	8.63	1.03	....	....	2 53	17.31	1930	189
1931	850	951,426	38.4	31.5	64.0	3 68	4.40	0 36	5.99	0.78	..	. .	2 44	13.19	1931	
1932	850	998,200	41.4	32.8	64.1	2.76	3.38	0.82	5 86	0.34	..	..	1 46	11.52	1932	
1933	850	956,138	38.5	32.8	61.6	3.61	4.57	0.70	6.24	0.34	. ..	..	0.55	12.06	1933	
1930	840	49,340	2.2	....	....	4.08	7.70	1.01	44.30	11.92	.. .	....	24.43	77.44	1930	153
1931	840	557,470	12.1	. .	.	3.41	3.46	0.61	4.71	0.90	....	. .	1 83	10.61	1931	
1932	840	929,460	19.7	82.7	23.6	3.55	3.18	0.53	2.65	0.78	...	.	1 24	7.60	1932	
1933	840	60,200	1.7	....	....	4.00	4.70	1.66	25.76	6.48	....	...	17.91	50 03	1933	
1931	840	915,865	21.4	76.8	24.7	3.56	3.09	0 34	1 59	0.70	0.61	0.28	1 59	6 61	1931	494
1932	840	482,220	11.3	74.5	13.4	3 51	3 38	0 54	1.88	0.87	0.60	1.22	2 69	8 49	1932	
1933	840	369,381	7.8	78.4	9.7	4.20	3.69	0.46	2.22	0.71	0.79	1.28	2.78	9 15	1933	
1932	900	719,930	26.9	38.2	36.2	2 76	4.57	0.74	6.79	0.32	2.26	0.19	2 77	14 87	1932	560
1933	900	670,266	25.3	39.0	34.3	2.98	4.15	0.74	6.74	0.45	0.71	0	1.16	12 79	1933	
1931	840	828,880	18.1	74.1	23.9	3 72	3 21	0 65	1.66	0.85	1.70	0	2.55	8 07	1931	619
1932	840	575,200	12.2	76.5	15.5	3.53	3 51	0 37	1 96	1.06	1.55	0.32	2 93	8 77	1932	
1933	840	390,760	8.2	82.3	9.9	4 28	3 34	0 66	2.59	1.01	0.52	0.28	1 81	8.40	1933	
1930	840	2,122,057	46.5	92.5	50.2	4 10	4 13	0 56	1.61	0 15	....	....	0 37	6 67	1930	1056
1931	840	1,906,182	41.5	76 2	55.0	3 84	3 70	0 51	1 56	0.50	0.66	0.28	1.44	7 21	1931	
1932	840	1,655,114	34.0	76 2	47.4	3 12	3 09	0 23	1.80	0 62	0.42	0.24	1 28	6.40	1932	
1933	840	379,021	8.1	62.3	13.8	3.50	3 65	0 29	4.96	2.10	....	....	5 86	14.76	1933	
1930	825	454,041	9.2	49.2	18.7	5.75	5 96	1.84	9.43	0.37	1.56	0	1.93	19.16	1930	731
1931	825	592,895	11.8	61 2	20 8	4.84	4.91	1 00	6 58	0 23	0 59	0	0 82	13 31	1931	
1932	825	554,765	11.1	68 2	17.7	4 00	3 70	1 17	7.50	1.20	1 63	0 09	2 92	15 29	1932	
1933	825	462,470	9.1	68.0	14.5	5 29	5 05	1 70	8 59	1 31	0 52	1 05	2 88	18 22	1933	

TABLE II—COMPARATIVE COSTS—1929, 1930, 1931, 1932 AND 1933 REPORTS (Page 4)

Plant No.	Year	Total Installed B.H.P.	Total Net Output K.W. Hrs.	Annual Plant Load Factor	Running Plant Capacity Factor	Plant Service Factor	Aver. Cost Fuel Oil—Cents per Gallon	Costs per Net K. W. Hr.—Mills: Fuel Cost	Lub. Oil Cost	Atten. Cost, Incl. Superint.	Cost Supplies & Misc., Incl. Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Total All Supply Repair & Misc. Costs	Total Production Cost	Year
648	1931	800	1,180,517	32.1	80.9	31.7	3.53	3.23	0.38	2.97	0.76	0.02	0.06	0.84	7.42	1931
	1932	800	1,068,900.	31.3	70.2	33.2	3.23	3.12	0.39	3.13	0.40	0.46	0.11	0.97	7.61	1932
	1933	800	1,095,200	32.1	67.6	35.4	3.90	3.64	0.43	2.84	0.28	0.16	0.05	0.49	7.40	1933
112	1930	740	1,165,300	29.7	68.1	42.2	4.43	5.19	0.83	5.46	0.19	0.54	0.12	0.85	12.33	1930
	1931	740	1,195,128	34.8	71.3	41.8	3.42	3.47	0.74	5.38	0.18	0.35	0.25	0.78	10.37	1931
	1932	740	1,443,130	41.9	75.8	46.7	3.52	3.57	0.64	4.19	0.23	0.06	0.04	0.33	8.73	1932
	1933	740	1,104,807	34.1	63.1	43.4	3.78	3.94	0.69	5.28	0.25	0.31	0.05	0.61	10.52	1933
67	1929	720	1,163,600	64.0	79.1	33.7	5.94	6.03	0.55	1.60	0.21	0.04	0	0.25	8.43	1929
	1930	720	1,098,900	58.4	82.9	30.3	4.97	4.73	0.71	1.70	0.23	1.03	0.02	1.28	8.42	1930
	1931	720	891,200	48.5	82.3	25.6	4.58	4.38	0.87	2.09	0.24	1.05	0.10	1.39	8.73	1931
	1932	720	810,190	44.0	81.5	23.4	4.47	4.39	0.94	2.30	0.30	1.04	0.12	1.46	9.09	1932
	1933	720	832,067	45.3	83.8	23.4	5.34	5.40	0.86	2.24	0.34	0.76	0.17	1.27	9.77	1933
170	1930	720	860,110	19.5	64.7	32.7	6.51	7.28	0.89	2.50	0.12	1.30	0	1.42	12.09	1930
	1931	720	835,219	22.4	64.5	31.6	6.20	6.78	0.78	2.19	0.20	2.64	0	2.84	12.59	1931
	1932	720	675,376	17.4	58.2	28.5	5.53	6.01	0.84	2.71	0.22	....	....	1.63	11.19	1932
	1933	720	780,252	19.8	55.8	34.5	4.95	4.84	0.77	2.42	0.32	....	....	1.35	9.38	1933
527	1930*d*	720	673,300	....	37.0	56.2	3.87	5.02	1.59	3.97	0.25	0.04	0.04	0.33	10.91	1930*d*
	1931	720	933,200	31.9	41.4	60.5	2.83	3.35	0.82	3.48	0.29	0.13	0.01	0.43	8.08	1931
	1932	720	967,000	31.1	39.6	59.2	3.10	3.52	0.81	5.08	0.24	0.25	0.03	0.52	9.93	1932
	1933	720	864,300	31.6	42.4	50.9	3.23	3.71	0.87	3.82	0.91	0.34	0.06	1.31	9.71	1933
718	1930*d*	720	604,312	....	36.9	51.5	4.27	6.05	1.33	6.50	0.83	1.70	0.58	3.11	16.99	1930*d*
	1931	720	691,477	38.6	34.9	51.4	3.45	4.66	1.33	5.04	0.68	6.28	0.14	7.10	18.13	1931
	1932	720	644,337	51.0	33.0	51.2	3.61	4.98	1.02	5.39	0.64	1.05	0.77	2.46	13.85	1932
	1933	720	658,898	41.7	33.5	51.3	3.76	5.53	1.13	5.52	0.25	1.15	0.10	1.50	13.68	1933
19	1929	700	603,260	29.8	....	....	4.50	6.32	1.40	5.40	1.07	....	....	2.24	15.36	1929
	1930	700	710,280	34.9	....	....	4.13	5.72	1.26	4.96	1.07	....	....	4.05	15.99	1930
	1931	700	694,060	34.8	....	....	3.73	5.27	1.47	5.15	0.80	....	....	5.59	17.48	1931
	1932	700	612,980	36.7	48.5	33.1	3.63	4.87	1.35	4.96	1.01	....	....	1.68	12.86	1932
	1933	700	579,880	38.8	....	....	4.08	5.61	1.31	5.18	0.69	....	....	2.37	14.47	1933
529	1932	620	507,836	34.3	38.4	38.6	3.60	5.28	0.93	6.21	1.92	0.21	0.20	2.33	14.75	1932
	1933	620	524,025	35.4	39.4	38.9	4.00	5.34	0.62	7.45	2.01	0.60	0.19	2.80	16.21	1933
32	1932	600	402,600	10.5	77.9	15.0	5.45	5.09	0.61	10.95	0.17	0.29	0	0.46	17.11	1932
	1933	600	706,050	18.4	72.8	28.3	6.00	5.43	1.26	5.52	0.08	0.05	0	0.13	12.34	1933
61	1930	600	1,539,900	....	52.3	79.6	6.39	5.31	0.59	5.53	0.33	0.61	0.06	1.00	12.43	1930
	1931	600	1,555,200	38.7	68.4	64.7	4.20	3.46	0.36	5 37	0.11	1.07	0	1.18	10.37	1931
	1932	600	1,380,330	37.9	64.3	60.7	4.63	3.97	0.38	5.76	0.04	1.02	0.03	1.09	11.20	1932
	1933	600	1,188,400	32.7	56.2	63.4	4.98	4.62	0.52	2.85	0.30	0.50	0	0.80	8.79	1933
106	1929	600	750,419	....	....	....	4.66	4.75	0.66	2.66	0.61	....	....	2.62	10.69	1929
	1930	600	1,435,434	35.6	....	....	4.49	4.18	0.27	3.09	0.65	....	....	2.52	10.06	1930
	1931	600	1,504,859	28.1	....	....	3.97	3.71	0.24	3.05	0.68	....	....	1.76	8.76	1931
	1932	600	1,358,285	31.5	71.4	55.8	3.77	3.57	0.27	3.07	0.74	....	....	2.07	8.98	1932
	1933	600	1,522,216	39.0	71.8	62.0	4.31	3.99	0.24	2.73	0.52	....	....	1.28	8.24	1933
1094	1931	600	678,530	19.5	78.5	25.3	3.84	3.43	0.27	2 65	0.91	1.80	0.37	3.08	9.43	1931
	1932	600	572,600	17.2	78.0	22.4	3.79	3.78	0.35	1.52	1.24	0.37	0.50	2.11	7.76	1932
	1933	600	583,920	16.6	89.4	18.9	4.18	3.43	0.34	1.39	0.60	0.71	0.24	1.55	6.71	1933
1096	1931	600	726,486	20.8	74.0	29.3	3.68	3.13	0.50	4.46	0.76	0.48	0.41	1.65	9.74	1931
	1932	600	708,626	19.7	69.9	29.3	3.88	3.39	0.50	2.09	0.65	1.45	0.27	2.37	8.35	1932
	1933	600	716,299	20.4	69.8	29.8	4.20	3.40	0.33	2.40	0.62	1.06	0.16	1.84	7.97	1933
862	1930	588	627,820	25.3	47.7	39.7	4.43	4.62	0.83	8.84	0.42	1.63	1.88	3.93	18.22	1930
	1931	588	640,360	25.7	46.9	41.7	3.27	3.81	0.70	10.77	0.40	1.24	0.97	2.61	17.89	1931
	1932	588	609,820	31.2	47.9	38.6	3.14	3.87	0.75	8.69	0.47	1.71	0.48	2.66	15.97	1932
	1933	588	609,080	33.3	44.9	42.1	3.44	4.33	1.00	9.18	0.81	4.08	0.40	5.29	19 80	1933
246	1930	540	364,500	28.8	....	....	6.47	11.42	2.69	9.80	0.69	0.14	0	0.83	24.74	1930
	1931	540	407,085	33.6	38.0	35.4	6.29	9.15	2.19	8.78	0.41	0.35	0	0.76	20.88	1931
	1932	540	412,636	30.7	35.1	38.5	6.17	9.05	1.86	8.66	0.28	0.10	0	0.38	19.95	1932
	1933	540	397,000	29.4	33.9	38.4	5.34	7.65	1.80	7.83	0.27	0.10	0.08	0.45	17.73	1933
540	1931	540	713,333	32.9	....	....	3.30	4.10	1.72	5.52	0.35	0.38	0.06	0.79	12.13	1931
	1932	540	633,751	28.2	40.9	51.3	3.36	4.46	1.91	6.22	0.69	0.19	0	0.88	13.47	1932
	1933	540	666,616	28.6	41.0	53.7	3.55	4.64	2.08	5.46	0.74	0.06	0.06	0.86	13 04	1933
772	1931	500	222,100	9.5	74.5	10.7	3.72	3.67	0.68	9.55	3.41	3.67	0.56	7.64	21.54	1931
	1932	500	142,730	6.2	73.7	7.1	3.72	3.90	0.64	4.90	4.15	0.57	0.46	5.18	14.62	1932
	1933	500	103,495	3.8	73.8	5.0	4.36	4.57	1.35	6.74	5.32	3.27	1.19	9.78	22.44	1933
644	1932	600	846,916	40.4	59.8	43.1	4.04	4.53	0.98	4.02	0.75	0.04	0.06	0.85	10.38	1932
	1933	600	840,958	39.4	59.5	43.5	5.28	6.03	1.03	3.42	0.85	0.18	0.06	1.08	11.57	1933
424	1932	480	586,935	36.1	41.8	50.9	3.00	3.58	1.34	4.37	0.34	0.14	0	0.48	9.77	1932
	1933	480	621,800	34.5	47.0	50.2	3.00	3.43	1.32	4.39	0.24	0	0	0.24	9.38	1933
501	1930	480	403,022	32.5	40.6	37.5	5.50	7.58	1.80	10.58	0.40	0.14	0.31	0.85	20.81	1930
	1931	480	452,970	37.3	39.3	42.6	3.93	5.53	1.60	8.50	0.49	0.62	0.33	1.44	17.07	1931
	1932	480	421,162	33.4	37.9	41.7	4.71	6 85	1.94	8.37	0.40	1.04	0.39	1.83	18.99	1932
	1933	480	397,167	35.3	36.5	40.4	4.30	6.02	1.83	11.64	0.31	1.44	0.23	1.98	21.47	1933
695	1932	450	423,414	29.2	47.6	34.6	4.59	5.13	0.77	9.63	0.62	0	0	0.62	16.15	1932
	1933	450	440,760	31.6	48.8	35.3	4.81	5.26	1.24	9.39	0.67	2.90	0	3.57	19.46	1933
335	1932	430	490,130	38.9	37.1	53.4	3.11	3.20	0.71	7.15	1.26	0.03	0.03	1.32	12.38	1932
	1933	430	479,720	36.9	36.5	53.2	4.72	4.85	0.76	9.08	0.94	0.87	0.04	1.85	16.54	1933
247	1930	390	428,290	28.9	....	....	6.00	8.12	1.10	10.79	0.11	0	0	0.11	20.12	1930
	1931	390	480,204	25.1	44.6	47.1	4.62	6.03	1.01	9.62	0.05	0.40	0.26	0.71	17.37	1931
	1932	390	485,760	24.7	54.2	39.2	4.55	5.88	0.81	9.76	0.07	0.12	0.05	0.24	16 69	1932
	1933	390	486,820	24.9	43.4	49.1	5.50	7.03	0 44	9.74	0.28	0.18	0	0.46	17.67	1933
152	1932	360	Net Generation Negative in 1933.													

TABLE II—COMPARATIVE COSTS—1929, 1930, 1931, 1932 AND 1933 REPORTS (Page 5)

Year	Total Installed B.H.P.	Total Net Output K.W. Hrs.	Annual Plant Load Factor	Running Plant Capacity Factor	Plant Service Factor	Aver. Cost Fuel Oil—Cents per Gallon	Costs per Net K. W. Hr.—Mills: Fuel Cost	Lub. Oil Cost	Atten. Cost, Incl. Superint.	Cost Supplies & Misc., Incl. Water	Cost of Engine Repairs	Cost of All Other Plant Repairs	Total All Supply Repair & Misc. Costs	Total Production Cost	Year	Plant No.
1932*i*	350	297,000	....	....	....	4.15	5.02	2.18	11.84	0.82	0.10	0.03	0.95	19.99	1932*i*	187
1933	350	301,279	25.8	32.9	46.7	3.82	4.23	2.00	10.64	0.43	0.15	0.05	0.64	17.51	1933	
1931	350	437,000	...	....	....	5.00	6.69	0.65	6.86	0.51	0.17	0.69	1.37	15.57	1931	688
1932	350	432,500	29.3	42.6	49.8	3.93	5.32	0.45	8.32	0.12	0.25	0.12	0.49	14.58	1932	
1933	350	400,000	29.4	41.8	47.8	4.82	7.14	0.69	6.86	0.97	0.41	0.19	1.57	16.26	1933	
1931	345	109,735	7.2	66.2	8.4	3.79	4.74	0.71	9.97	3.03	6.09	1.07	10.19	25.61	1931	774
1932	345	77,122	5.1	72.6	5.5	3.58	3.31	1.03	6.57	3.52	1.36	2.97	7.85	18.76	1932	
1933	345	65,645	7.6	67.4	4.9	4.59	4.61	0.96	7.28	3.31	12.98	0.06	16.35	29.20	1933	
1930	330	307,163	44.3	....	....	3.39	5.91	2.06	11.50	1.75	1.22	0.84	3.81	23.28	1930	857
1931	330	No Reply to Inquiries for 1931.													1931	
1932	330	379,380	....	42.8	51.3	2.80	4.30	1.57	6.92	1.82	3.97	0.84	6.63	19.42	1932	
1933	330	369,378	42.8	40.8	51.9	3.25	5.36	1.71	7.39	1.79	6.12	0.70	8.60	23.07	1933	
1930	180	184,000	....	....	....	9.14	13.48	1.76	13.58	1.10	0.71	0	1.81	30.63	1930	265
1931	320	216,000	....	....	37.0	7.79	11.81	1.83	11.57	0.32	0.46	0.58	1.36	26.57	1931	
1932	320	220,000	25.4	37.9	34.3	7.30	11.00	1.86	11.37	0.16	0.11	0.34	0.61	24.84	1932	
1933	320	257,000	26.0	39.6	35.2	7.35	9.59	1.41	11.67	0.19	0.70	0.14	1.03	23.70	1933	
1932*k*	320	204,875	....	29.6	100.0	4.50	5.79	1.49	8.30	0.46	0	0	0.46	16.04	1932*k*	1055
1933	320	421,352	33.1	28.4	97.5	4.32	7.27	0.47	11.29	0.54	0	0.05	0.59	19.62	1933	
1930	315	190,375	30.1	....	....	4.93	9.00	2.42	12.68	0.77	....	....	6.68	30.78	1930	27
1931	315	208,890	30.8	....	....	4.06	7.72	1.52	10.58	0.95	....	....	7.29	27.16	1931	
1932	315	194,105	32.0	28.8	39.4	3.63	7.12	3.05	11.06	0.92	....	....	13.05	34.28	1932	
1933	315	186,510	31.0	....	....	4.14	7.29	2.13	10.88	0.77	....	....	5.93	26.23	1933	
1931*l*	300	86,887	....	20.5	37.4	3.35	3.62	0.82	4.47	0.43	0	0	0.43	9.34	1931*l*	382
1932	300	99,300	....	21.2	28.4	3.48	4.76	0.66	5.08	0.42	0	0	0.42	10.92	1932	
1933	300	251,413	....	27.2	52.6	3.64	3.63	0.50	3.73	0.19	0.02	0	0.21	8.07	1933	
1930	180	123,538	23.0	....	....	3.41	6.87	3.26	31.90	4.02	4.66	2.08	10.76	52.79	1930	858
1931	180	No Reply to Inquiries for 1931.													1931	
1932	270	175,200	....	26.7	49.7	2.82	6.46	2.78	17.45	3.31	1.54	0.43	5.28	31.97	1932	
1933	270	172,400	39.6	26.7	49.6	3.12	7.17	3.13	16.40	3.81	6.85	1.00	11.66	38.36	1933	
1930	240	151,850	11.3	41.5	27.1	5.98	6.23	0.94	2.56	0.55	0.51	0	1.06	10.79	1930	169
1931	240	184,360	13.7	42.5	31.9	5.56	6.23	0.89	2.11	0.87	4.39	0	5.26	14.49	1931	
1932	240	77,310	5.8	27.7	20.9	5.04	6.52	1.25	3.84	0.85	....	....	14.77	26.38	1932	
1933	240	79,570	6.0	28.8	20.7	4.50	6.34	1.13	4.52	0.98	....	....	9.72	21.71	1933	
1932	225	27,290	1.6	47.1	4.6	4.50	6.43	0.57	5.22	1.10	0	0	1.10	13.32	1932	984
1933	225	26,851	1.8	48.5	4.5	4.29	5.07	0.60	5.59	0.75	0.82	0.19	1.76	13.02	1933	
1932	212.5	138,700	29.9	....	....	4.10	6.81	1.89	15.14	2.78	0.23	0.25	3.26	27.10	1932	318
1933	212.5	139,730	26.6	....	....	3.69	6.81	2.37	13.43	2.00	0.34	1.20	3.54	26.15	1933	
1930	175	14,800	1.6	65.0	1.6	4.82	5.54	2.91	8.92	2.91	0	0	2.91	20.28	1930	733
1931	175	3,293	0.3	62.5	0.5	5.78	10.93	0.91	10.93	9.72	0	0	9.72	32.49	1931	
1932	175	1,788	0.2	62.1	0.3	3.00	7.92	1.96	18.18	34.30	0.56	20.43	55.29	83.35	1932	
1933	175	1,892	0.2	53.2	0.4	6.03	16.00	3.17	38.34	20.20	0	37.20	57.40	114.91	1933	
1930	120	15,893	3.8	13.7	7.0	7.00	12.65	3.15	147.25	11.26	0	0	11.26	174.31	1930	646
1931	120	21,035	5.3	16.1	20.4	7.00	16.70	2.57	16.97	3.28	0	0	3.28	39.52	1931	
1932	120	5,832	1.6	13.4	7.6	5.37	18.82	5.70	27.14	0	0	0	0	51.66	1932	
1933	120	8,074	....	11.1	11.4	5.39	14.62	4.34	21.92	12.87	9.91	8.55	31.33	72.21	1933	

Plant 54 did not operate in 1933. Purchased Power of Dump Power Contract.

Following Plants were used for Standby Power only in 1933: 735-736-738.

" " Data for 1933 was not received: 132-451-626-863.

" " did not submit sufficient Data for 1933: 161-532-1129-83.

" " made no reply to inquiries for 1933: 3-14-91-92-93-95-96-98-101-102-103-105-143-160-193-333-411-516-720-908-1016-1091.

NOTES:

a— 8.1 months
b—13 months
c— 6 months
d—10 months
e— 6.7 months
f—36 months
g—11 months
h—12.1 months
i—12.8 months
k— 5 months
l— 8 months

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 1)

	Engine Data													Lubrication					Fuel				
Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
43	1	4	A	..	TP	500	336	3	22 x29½	150	375	1915	93	155	19	.....	300		2,162	20.1°API	No	21,456	138
	2	4	A	.	TP	500	336	3	22 x29½	150	375	1916	157	183	35	.....	429	S	3,232	75.5 SSF @ 77F	No	34,720	190
	3	4	A	..	TP	520	349	4	19 x24½	200	500	1919	255	171	63	.....	776	&	7,406	1.1%S; 0.02% Ash	No	68,710	402
	4	4	A	.	TP	520	349	4	19 x24½	200	500	1920	254	236	64	.....	560	F	7,114	0.05% BS&W	No	65,930	279
	5	4	A	..	CHa	1,000	671	6	20½x36	150	925	1922	465	429	196	.....	1,083		19,514	19.3% Asphaltic Residue	No	197,810	461
	6	4	A	..	CHa	1,000	671	6	20½x36	150	925	1925	132	366	81	.....	361		6,975	after ½ hour @ 400C	No	57,210	156
	7	2	A	P	CH	3,750	2,517	6	30 x42	124	3,750	1928	5,250	7,144	2,553	.....	2,755		826,012	1.91% hard asphalt	No	10,024,400	1,403
	8	2	A	B	CH	3,750	2,517	6	30 x42	124	3,750	1929	2,430	3,831	1,224	.....	2,376	CC	359,831		No	4,650,700b	1,213b
	9	2	M	B	CH	4,100	2,753	6	30 x42	124	3,750	1932	7,803	9,737	3,347	.....	3,285		1,094,781		No	15,674,800b	1,610b
	Plant					15,640	10,499				14,850			22,252	7,582	.....	2,778		2,327,027			30,795,736b	1,383b
82	1	4	A	..	TP	360	242	4	16½x21	225	312	1921	808	86	81	.....	3,380		11,992	33.7°API	No	113,000	1,313
	2	2	A	P	CH	750	504	4	17 x27	180	740	1923	1,346	276	227	.....	3,657		39,826	40.5 SSU @ 100F	No	336,030	1,217
	3	2	A	P	CH	750	504	4	17 x27	180	740	1924	1,146	216	194	.....	3,977		31,237	0.38% S; 0.06% CC	No	284,300	1,316
	4	2	A	P	CH	1,150	772	6	17 x27	180	1,000	1927	2,699	645	543	.....	4,810	BC	102,266	0.004% Ash	No	995,130	1,542
	5	2	A	P	CH	1,150	772	6	17 x27	180	1,000	1927	2,696	1,384	584	.....	2,239		119,717	BS&W—Trace	No	1,287,390	930
	6	2	A	P	CH	1,500	1,007	8	17 x27	180	1,350	1929	2,739	1,556	723	.....	2,639		172,891		No	1,899,600	1,220
	7	2	M	B	TP	3,300	2,216	10	19½x27	240	2,960	1932	3,362	3,019	2,473	.....	3,674		359,547		No	5,080,100b	1,683b
	Plant					8,960	6,017				8,102			7,182	4,825	1,952	3,282		837,476			9,995,550b	1,391b
52	1	4	A	..	CHa	830	557	4	23 x32	164	700	1928	3,508	610	329	0	4,774		118,998	25.6° API	No	1,371,500	2,250
	2	4	A	..	CHa	1,250	840	6	23 x32	164	1,060	1928	4,379	970	598	0	5,645	BC	243,557	0.6% S; 0.3% CC	No	2,880,600	2,970
	3	4	A	..	CHa	1,250	840	6	23 x32	164	1,060	1928	2,360	698	322	0	4,225	&	128,720	0.6% BS&W; Ash—Trace	No	1,500,700	2,150
	4	4	A	..	CHa	1,250	840	6	23 x32	164	1,060	1930	2,900	730	397	0	4,965	S	163,760		No	1,909,400	2,615
	5	4	A	..	CHa	2,865	1,924	8	29 x48	120	2,500	1933d	1,380	823	395	0	4,805		182,651		No	2,287,600	2,780
	Plant					7,445	5,001				6,380			3,831	2,041	0	4,935		837,686			9,949,800	2,595
73	1	2	A	P	CH	1,250	840	5	20¾x26	180	1,125	1924	2,247	766	175	0	3,667		125,364		No	1,272,500	1,661
	2	2	A	P	CH	1,250	840	5	20¾x26	180	1,125	1926	2,616	927	225	0	3,528	CC	147,877	10-14° API	No	1,516,300	1,636
	3	2	A	P	CH	1,250	840	5	20¾x26	180	1,125	1928	5,181	1,549	363	0	4,181	&	280,072		No	2,805,800	1,811
	4	2	A	P	CH	1,250	840	5	20¾x26	180	1,125	1928	5,765	1,525	367	0	4,725	F	332,239		No	3,327,000	2,182
	Plant					5,000	3,360				4,500			4,767	1,130	0	4,145		885,552			8,921,600	1,872
45	1	4	A	..	TP	600	403	6	16½x24	200	500	1923	49	24	.....	.....	1,225	BC,	696	21.2° API; 65 SSU @ 122F;	No	9,850	411
	2	4	A	..	TP	600	403	6	16½x24	200	500	1923	148	44	.....	.....	2,018	C&F	2,682	7.74% CC; 1.47% S	No	24,475	556
	3	4	A	..	CHa	750	504	4	23 x32	150	625	1923	2,548	460	405	.....	4,154		60,058	2.5% BS&W	No	581,600	1,262
	4	4	A	..	CHa	1,150	772	6	23 x32	150	1,000	1926	4,677	682	572	.....	7,880	BC	195,146		No	2,101,650	3,080
	5	4	A	..	CHa	1,150	772	6	23 x32	150	1,000	1926	4,907	665	553	.....	8,485	&C	216,707		No	2,266,750	3,408
	Plant					4,250	2,854				3,625			1,875	.....	.....	6,960		475,289			4,984,325	2,658
111	1	4	A	..	TP	675	453	6	17 x24	225	580	1928	4,251	....	.....	.....	....		....	19.4° API	No	1,163,200	......
	2	4	A	..	TP	900	604	8	17 x24	225	770	1928	2,921	....	.....	.....	....	CC	....		No	1,165,100	......
	3	4	A	..	TP	900	604	8	17 x24	225	770	1928	3,026	....	.....	.....	....	&	....		No	1,167,600	......
	4	4	M	..	TP	1,200	806	6	20 x24	277	1,040	1932	3,225	....	.....	.....	....	S	....		No	1,640,000	......
	Plant					3,675	2,467				3,160			3,700	800	50	3,270		433,188			5,135,900h	1,385h
130	1	4	A	..	TP	600	403	6	16½x23	225	513	1924	5,816	1,694	220	0	2,058		145,990	16°—30° API	No	1,592,800	940
	2	4	A	..	TP	600	403	8	17 x24	200	513	1926	4,571	1,150	210	0	2,383	BC	111,322	0.9% S	No	1,197,200	1,041
	3	4	A	..	TP	1,200	806	6	20 x24	300	1,062	1929	2,068	1,115	198	0	2,225	&	108,700		No	1,153,100	1,033
	4	4	A	..	TP	1,200	806	6	20 x24	300	1,062	1930	2,321	1,571	253	0	1,773	CC	124,930		No	1,295,300	825
	Plant					3,600	2,418				3,150			5,530	881	0	2,078		490,942			5,238,400	947
157	1	2	A	P	CH	1,760	1,182	8	17 x23	257	1,500	1930	1,109	....	.....	.....	....	S	98,122	24°—26° API	No	1,068,500	......
	2	2	A	P	CH	1,760	1,182	8	17 x23	257	1,500	1930	1,079	....	.....	.....	....	&F	94,834		No	1,093,600	......
	Plant					3,520	2,364				3,000			1,263	495	.....	3,049		192,956			2,162,100	1,711
2	1	4	A	..	TP	1,150	772	6	23 x29½	166⅔	1,000	1925	2,266	....	.....	0	....	CC	155,699	27° API; 40 SSU @ 100 F	No	1,690,240	......
	2	4	A	..	TP	1,150	772	6	23 x29½	166⅔	1,000	1925	2,251	....	.....	0	....	&S	151,270	0.5% S; 2.0% CC;	No	1,690,240	......
	3	4	A	..	TP	1,150	772	6	23 x29½	166⅔	1,000	1925	2,236	....	.....	0	....		151,598	0.04% Ash; Tank Wagon	No	1,691,240	......
	Plant					3,450	2,316				3,000			3,367	1,687	0	2,306		458,567	Deliv.		5,071,720	1,506
164	1	4	M	..	TP	840	564	6	19½x24	214	1,000	1926	7,244	....	.....	.....	....		....	28° API; 42 SSU @ 100 F;	No	3,502,300	......
	2	4	M	..	TP	840	564	6	19½x24	214	1,000	1926	7,217	....	.....	.....	....	BC	....	0.05% S; 0.028% CC;	No	3,436,300	......
	3	4	M	..	TP	840	564	6	19½x24	214	1,000	1926	7,574	....	.....	.....	....		....	0.001% Ash; BS&W—nil	No	3,802,200	......
	4	4	M	.	TP	840	564	6	19½x24	214	1,000	1926	6,041	....	.....	.....	....		....	By Refinery Pipe Line	No	3,043,400	......
	Plant					3,360	2,256				4,000			17,069	.....	800	1,382		1,043,710			13,784,200	808
77	1	2	M	B	TP	3,000	2,014	10	19½x27	240	2,812	1931	7,316	5,575	5,103	0	3,936	CC&F	428,744	25.2°API; 50 SSU @ 100F; 0.4% S; 3.25% CC; 0.01% Ash; 0.75% BS&W	Yes	5,790,900b	1,038b
109	1	2	A	P	CH	675	453	4	16¾x22	240	500	1927	2,258	344	167	0	4,431		....		No	454,580	1,321
	2	2	A	P	TP	1,125	755	8	14⅞x21	257	975	1929	635	212	171	0	3,370	CC	....	24°—26° API; 0.5% S	No	231,650	1,093
	3	2	A	P	TPa	1,125	755	8	14⅞x21	257	975	1931	666	279	172	0	2,685		....		No	273,730	981
	Plant					2,925	1,963				2,450			835	510	0	3,578		117,502			959,960	1,150
7	1	4	M	..	TP	350	235	6	11½x16	277	375	1925	1,890	....	.....	.....	....		....	36°—40° API;	Yes	263,900	......
	2	4	M	..	TP	350	235	6	11½x16	277	375	1925	1,560	....	.....	.....	....		....	44.4 SSU @ 100 F;	Yes	210,600	......
	3	4	M	..	TP	350	235	6	11½x16	277	375	1925	1,226	....	.....	.....	....	CC	....	0.23% S; 0.016% CC;	Yes	169,000	......
	4	4	M	..	TP	750	504	6	16 x22	240	750	1927	3,747	....	.....	.....	....		....	0.012% Ash; 1.3% BS&W	Yes	940,800	......
	5	4	M	..	TP	930	624	6	18 x22	257	750	1930	4,584	....	.....	.....	....		....		Yes	1,775,600	......
	Plant					2,730	1,833				2,625			2,805	.....	420	3,104		284,995			3,359,900	1,197
732	1	4	A	..	TP	250	168	4	13¾x17½	257	200	1916	0	....	.....	.....	....		....	....	No	....	......
	2	4	A	..	TP	250	168	4	13¾x17½	257	200	1916	635	....	.....	.....	....	CC	....	....	No	....	......
	3	4	A	..	TP	520	349	4	19½x24½	200	400	1921	1,230	....	.....	.....	....	&F	....	....	No	....	......
	4	4	A	..	TP	750	504	4	23 x32	150	625	1923	1,600	....	.....	.....	....		....	....	No	....	......
	5	4	A	..	TP	750	504	4	23 x32	150	625	1926	2,000	....	.....	.....	....		....	....	No	....	......
	Plant					2,520	1,693				2,050			2,740	.....	.....	1,276		150,757			1,222,560	446
978	1	2	M	P	TP	840	564	6	16 x20	257	700	1931	.....	....	.....	.....	....	....	....	....	...	....	......
	2	2	M	P	TP	840	564	6	16 x20	257	700	1931	.....	....	.....	.....	....	....	....	....	...	....	......
	3	2	M	P	TP	840	564	6	16 x20	257	700	1931	.....	....	.....	.....	....	....	....	....	...	....	......
	Plant					2,520	1,692				2,100			135	.....	.....	....		14,295			184,300	1,365
679	1	2	A	P	CH	1,250	840	5	20¾x26	180	1,065	1925	1,053	707	66	.....	1,862	BC	80,521	28°—30° API	No	877,650	1,241
	2	2	A	P	CH	1,250	840	5	20¾x26	180	1,065	1925	964	696	38	.....	1,732	&S	75,776	75 SSU @ 100 F	No	800,250	1,150
	Plant					2,500	1,680				2,130			1,403	104	.....	1,797		156,297			1,677,900	1,196

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 1, Continued)

Loading												Maintenance and Repairs									Attendance					
Factor (See Text)	Running Plant Capacity Factor (See Text)	Peak Load During Reported Period—Gross K.W.	B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used?	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
.7		300	78 4	70 0	W	No						104	587	0	0	0 69	....	0	0	101						43
.8		300	78.4	70 0	W	No								0	0		....	0	0	170						
.2		400	74.0	84.8	W	No						2	397	0	0	0 38	....	0	0	99						
.4		400	74 0	84.8	W	No								0	0		....	0	0	98						
.4		740	73 9	81 5	W	No						130	323	0	0	0.23	....	0	0	123						
.6		740	73.9	81 5	W	No								0	0		....	0	0	36						
.9		3,000	67.2	80 1	W	Yes								0	0		Cyl.Liners; 1-Cyl.Head	0	0	796	317½	8	2			
1		3,000	67 2	80 1	W	Yes						— 18,921 —		0	0	1 63	1-Liner	0	0	486	317½	8	3			
.0		3,000	73 5	80.1	W	Yes								0	0		Fuel V.; Starting V.	0	0	892	317½	8	2			
	74.3	6,400c					B-F	90	130	N	N										317½	8	1	1,350	2,500	
.8		260	72.7	78.1	A	No						44	420	0	0	1.29	8-Piston Rings	1	5½	91						82
.5		400	67.3	53.4	W	Yes						64	490	0	0	0.74	(See gg1)	0	0	0						
.2		410	67.3	54 8	W	Yes						26	363	0	0	0.52	1-Piston Cooling Tube	0	0	0						
.8		745	68.8	66.4	W	Yes						731	1,178	0	0	1.66	(See gg2)	0	0	1,104	313	8	2			
.8		755	68 8	67 3	W	Yes						961	1,819	0	0	2.42	(See gg3)	1	2½	1,393	313	8	2½			
.9		1,060	67.3	70.8	W	Yes						988	2,182	410	540	2.75	(See gg4)	1	210	2,568	313	8	4½			
.2		2,220	67.6	67.8	O	Yes						355	1,759	0	0	0.64	(See gg5)	4	34	16	208	8	1			
	63.2	3,360					B-F	75	115	N	N					1.38					156	8	1	354	23	
.1		560	75 3	75.7	W	Noe						54	410g	0	15g	0.58	Exh.V. Seat & Sp.	1	2	81						52
.3		860	75 7	77.5	W	Noe						106	818g	176	187g	1.03	(See gg6)	2	873f	188	313	8	2			
.7		860	75.7	77.5	W	Noe						409	839g	0	32g	1.02	(See gg7)	1	1	176	313	8	2			
.4		850	75 7	76 6	W	Noe						101	683g	0	0	0.63	Exh. Valve Springs	0	0	157	313	8	3			
1		2,280	74 5	88.3	W	Noe						28	697g	0	0	0.25	None	0	0	248	312	8	1			
	78.3	3,020					B	90	115	N	B/W					0.61					52	8	1	466	30	
.4		900	62 5	67 0	W	Yes						1,750	0	0	0	1.40	1-Set Cylinder Liners;	0	0	......	.....	7	....			73
.0		900	62 5	67.0	W	Yes						300	0	0	0	0.24	2-Main Bearings;	0	0	......	.....	6	....			
.5		900	62.5	67.0	W	Yes						285	0	0	0	0.23	Piston Rings;	0	0	......	....	6	....			
.7		900	62 5	67.0	W	Yes						420	0	0	0	0.34	Scavenging Valves	0	0	.....	.....	6	....			
	67.2	2,300					B-F	80	120	F	B					0 55				......	.....	6	....	.....	500	
.0		275	77.2	52.6	A	Noe								0	0		None	0	0	16						45
.1		400	77.2	76.6	A	Noe								0	0		None	0	0	18						
.4		350	74 5	51.7	W	Noe						410	398	622	27	0.41	Cylinder Head	0	0	127	313	8	2			
.2		700	76.1	69 0	W	Noe								241	51		Piston Rod	0	0	381	313	8	4			
.9		700	76.1	69 0	W	Noe								0	0		None	0	0	288	313	8	2			
	56.9	1,600					B	85	100	N	N										313	8	1	198	50	
.4		460	72 6	73 7	A	Yes											Piston Rings & Gaskets	0	0	50						111
.1		600	72 6	72.1	A	Yes						—1,132—				0 31		0	0	45	313	8	2			
.8		600	72 6	72.1	A	Yes												1	1	29	313	8	2			
.1		800	75.8	75.3	O	No												1	2	28	313	8	2			
	63.2	1,500					C	95	120	N	B										313	8	1	259	200	
.9		450	73.8	82.4	A	Yes						512	10	0	0	0.87	Rocker Arms; A.C.; A.V.	1	8	112	.....					130
.0		430	72.7	77.6	A	Yes						122	0	0	0	0.20	Pump Plungers	5	40	130	.....	8	....			
.1		960	70.1	83.5	O	Yes						381	18	0	0	0.33	Pu. Pl.; Sc.; A. C. R. W. P.	2	72	68	.....	8	...			
.2		1,010	70.1	87.8	O	Yes						622	130	0	0	0.63	Main B.; Sc.; A. C.;	5	120	124	.....	8	....			
	67.8	1,370					A	60	110	N	L					0.50	A. C. R.				.....	8	....	.....	750	
.5		1,250	64 9	68 6	O	Yes						689	0	0	0	0.20	Comp.Valves & Spgs.;	1	1	.....	....					157
.8		1,300	64.9	71.4	O	Yes							0	0	0		Scavenging Valves;	0	0	......	365	8	1			
	83.6	2,300					A/Ci	34/85	100—120	N	B/F						Rings				365	8	1	364	1,016	
.6		785	74.3	75.6	W	No								0	0		Injection; Inlet &	1	2½	......						2
3		785	74 3	75 6	W	No						888	916	0	0	0.52	Exhaust Valve parts;	1	2½	......	....	8	...			
.0		785	74.3	75.6	W	No								0	0		Pipe; Misc.	2	3½	......	.....	8	...			
	97.3	2,355					A	63	110	N	L										.....	12	....	.....	735	
7		538j	72 4	....	O	No											....	....	...	....	234	8	3			164
.4		567j	72.4	..	O	No							—23,94—			7.13	....	....	....	......	234	8	3			
.0		554j	72.4	....	O	No											....	....	....	......	234	8	3			
.3		542j	72.4	....	O	No											1-Con. Rod; 1-Cyl.;	....	....	......	234	8	3			
	87.0	2,083j					D	110	130	N	N						1-Piston; ½-Base				156	8	3	507	30	
.3	39.3	1,700	61 4	51.8	O	Yes	D-F	96	120	N	N	1,965	1,800	0	0	1.26	(See gg8)	2	548	896	305	8	3	264	4,000	77
																					305	8a	2			
.4		430	57.4	54.5	O	No								0	0			0	0	240						109
.3		700	59 4	55.1	O	Yes						620	123	0	0	0.25	Pistons	1	5	435	365	8	1½			
.4		700	59.4	55.1	O	Yes								0	0			0	0	136	365	8	1			
	47 9	1,150					B	90	110	N	N										365	8	1	91	4,300	
4		225	100.3	96.0	A	Yes								0	0		Spray Valve Bushings;	0	0	9						7
5		225	100.3	96.0	A	Yes								0	0		Fuel Pump Bodies;	0	0	149						
7		225	100.3	96.0	A	Yes						540	320	0	0	0.82	Fuel Pump Plungers	0	0	401						
8		400	93.2	74.0	A	Yes								1,120	261		1-H.; 1-L.; 1-P. & R.; R	1	99	80	365	8	2			
1		580	85.2	79.2	A	Yes								0	0			0	0	63	365	8	2			
	57.5	922					Dk	60	120	N	N						Liner Gaskets				365	8	2	178	1,230	
		...	74.1	....	A	Yes							0	0	0			....	....	......						732
		.....	74.1	....	A	Yes							0	0	0			....	....	......						
		.....	70.4	....	W	Yes						2,787	0	0	0	1.11	1-Cyl. Head	....	....	......	313	8	2			
		....	74 5	....	W	Yes							0	0	0			....	....	......	313	8	3			
		...	74.5	...	W	Yes							0	0	0			....	....	......	313	8	2			
	52.0	1,400					B	......	......	N	N										313	8	1	49	850	
		......	53 6	....	O	....						......	......	......	......	......	....	....	....	......	.....	....	....			978
			53 6	..	O	.																				
		....	53 6	..	O																					
		1,100																						22	.....	
.3		975	62 5	72 6	W	No						740	408	0	0	0.46	Pistons	0	0	104						679
.8		925	62.5	68 9	W	No								0	0			0	0	56	191	8	1¾			
	99 2	1,850					A	70l	130	N	N										83	8	2	.....	603	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 2)

Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
ENGINE DATA														LUBRICATION					FUEL				
60	1	4	M		TP	800	537	8	19½x22	200	675	1924	2,145	...	...	...	...		...	...	No	223,000	...
	2	4	M	..	TP	800	537	8	19½x22	200	675	1924	2,824	...	...	...	...	BC	...	...	No	356,200	...
	3	4	M	..	TP	800	537	8	19½x22	200	675	1924	3,122	...	...	...	...		...	...	No	360,500	...
	Plant					2,400	1,611				2,025			2,143	...	887	3,020		148,009			939,700	438
1149	1	2	M	P	TP	1,200	806	8	16 x20	257	1,050	1932	...	...	...	...	...	...	...	...	...	...	...
	2	2	M	P	TP	1,200	806	8	16 x20	257	1,041	1932	...	...	...	...	...	...	...	...	...	...	...
	Plant					2,400	1,612				2,091			100	...	...	...		24,750			290,760	2,908
41	1	4	A	..	TP	520	349	3	22 x29½	164	400	1922	3,520	...	...	...	...	CC	70,900	20° API	No	673,990	...
	2	4	A	..	TP	700	470	4	22 x29½	164	500	1923	3,073	...	...	...	...	S,	75,990	47 SSU @ 100 F	No	786,200	...
	3	4	A	..	TP	1,150	772	6	23 x29½	164	900	1928	3,761	...	...	...	...	&F	187,126	1.3% S; 0.15% CC	No	1,869,600	...
	Plant					2,370	1,591				1,800			4,689	930	...	1,770		334,016			3,329,790	710
723	1	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1925	199	42	...	...	1,421	BC&F	3,320		No	32,030	763
	2	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1925	341	68	...	...	1,504	BC&F	4,845	32°—36° API	No	46,480	684
	3	2	M	P	TP	720	484	6	16 x20	257	600	1927	1,205	615	...	...	1,411	BC	41,175		No	406,200	660
	4	2	M	P	TP	1,050	705	7	16 x20	257	910	1931	1,733	725	...	...	2,510	BC	80,285		No	926,800	1,278
	Plant					2,370	1,593				2,010			1,450	...	...	1,965		129,625			1,411,510	973
34	1	2	M	P	TP	750	504	5	16 x20	257	640	1932	3,382	...	...	...	...		93,500		No	1,026,760	...
	2	2	M	P	TP	750	504	5	16 x20	257	640	1932	3,501	...	...	...	...	BC	94,100	32.5° API	No	1,050,750	...
	3	2	M	P	TP	750	504	5	16 x20	257	640	1932	3,494	...	...	...	...		96,853		No	1,071,590	...
	Plant					2,250	1,512				1,920			3,462	...	...	2,246		284,453			3,149,100	910
79	1	4	A	..	TP	225	151	3	16 x24	164	198	1911	1,191	360	15	...	744		11,505	24° API; 166 SSU @ 100° F	No	108,300	283
	2	4	A	..	TP	225	151	3	16 x24	164	198	1912	86	23	2	...	841		694	0.45% S; 4.3% CC	No		
	3	4	A		TP	600	403	6	16¼x23½	225	512	1929	5,024	772	202	100	3,905	S	105,545	Trace—Ash; BS&W—Nil	No	1,274,400	1,650
	4	4	A	..	TP	520	349	4	19 x26	200	438	1923	2,559	1,078	161	165	1,234		53,852		No	612,500	569
	5	4	A	..	TP	600	403	6	16¼x23½	225	512	1925	4,658	1,768	190	165	1,580		100,931		No	1,235,200	699
	Plant					2,170	1,457				1,858			4,001	570	...	1,856		272,527			3,230,400	807
5	1	2	M	P	TP	720	484	6	16 x20	257	...	1926	...	...	...	...	...	...	...	...	...	...	...
	2	2	M	P	TP	720	484	6	16 x20	257	...	1927	...	...	...	...	...	...	...	...	...	...	...
	'	2	M	P	TP	720	484	6	16 x20	257	...	1927	...	...	...	...	...	...	...	...	...	...	...
	Plant					2,160	1,452				...			946	...	...	...		95,288			918,180	971
6	1	2	M	C	TP	300 *m*	202	6	14 x17	257	...	1926	101	...	...	...	...	...	...	...	...	...	...
	2	4	A	..	TP	600	403	6	17 x25	200	...	1926	1,373	...	...	...	...	...	...	...	...	...	...
	3	4	A	..	TP	600	403	6	17 x25	200	...	1927	1,431	...	...	...	...	...	...	...	...	...	...
	4	4	A	..	TP	600	403	6	17 x25	200	...	1928	1,529	...	...	...	...	...	...	...	...	...	...
	Plant					2,100	1,411							1,388	...	...	1,895		141,204			1,652,500	1,191
68	1	2	M	C	TP	240	161	4	14 x17	257	200	1925	2,765	...	...	...	...		...		No	236,900	...
	2	2	M	C	TP	360	242	6	14 x17	257	300	1925	4,050	...	...	...	...	BC	...	30°—34° API	No	512,600	...
	3	2	M	P	TP	560	376	4	16 x20	257	470	1928	4,673	...	...	...	...		...		No	1,239,400	...
	4	2	M	P	TP	900	604	6	16 x20	257	774	1930	3,630	...	...	...	...		...		No	1,527,900	...
	Plant					2,060	1,383				1,744			3,622	...	97	2,209		361,270			3,516,800	971
133	1	4	A	.	TP	1,000	671	8	17½x24½	225	688*o*	1930	2,967	1,438	912	366	2,061	CC	134,400	24°API; 75 SSU @ 122F;	No	1,598,730	1,111
	2	4	A	..	TP	1,000	671	8	17½x24½	225	688*o*	1930	2,918	1,422	896	366	2,050		136,573	1.25% S; 0.5% CC;	No	1,625,820	1,142
	Plant					2,000	1,342				1,376*o*			2,860	1,808	732	2,057		270,973	0.05% Ash; 1.0% BS&W Delivered by Tank Wagon		3,224,550	1,127
806	1	4	A	..	TP	300	202	3	16½x24	200	240	1916	1,429	95	...	...	4,513	BC	23,187	24.9° API: 0.32% S	Yes	232,550	2,448
	2	4	A	..	TP	500	336	4	18⅞x28⅜	164	475	1921	3,744	422	...	...	4,436	&C	85,653	4.9% BS&W	Yes	906,670	2,149
	3	4	A	..	TP	1,200	806	6	20 x24	300	1,043	1930	5,151	3,351	...	...	1,845		257,111	Partly Delivered in Tank Trucks	Yes	2,842,300	848
	Plant					2,000	1,344				1,758			3,868	...	...	2,193		365,951			3,981,520	1,029
29	1	4	M	..	TP	660	443	6	16 x20	300	563	1932	1,206	306	...	...	2,600	CC	26,403	28°—32° B; 36 SSU @ 100F;	No	299,200	978
	2	4	M	..	TP	660	443	6	16 x20	300	563	1932	1,226	352	...	...	2,298	&S	26,146	0.6% S; 0.035% CC;	No	318,700	905
	3	4	M	..	TP	660	443	6	16 x20	300	563	1932	1,196	318	...	...	2,480		27,207	Trace—Ash; BS&W—Nil;	No	308,440	970
	Plant					1,980	1,329				1,689			976	...	...	2,454		79,756	Delivered by Tank Ship		926,340	949
215	1	2	M	P	TP	980	658	7	16 x20	257	845	1930	1,740	...	...	...	...	BC	...	33.5° API; 0.22% S	No	917,800	...
	2	2	M	P	TP	980	658	7	16 x20	257	845	1930	561	...	...	...	...		...	0.3% Ash	No	277,100	...
	Plant					1,960	1,316				1,690			738	...	...	3,055		104,059			1,194,900	1,619
807	1	4	A	..	TP	500	336	5	16½x24	200	425	1916	187	50	...	...	1,870		3,691		No	41,720	834
	2	4	A	..	TP	365	245	4	16¼x21	225	312	1921	204	60	...	...	1,241	BC	2,057	28°—30° API	No	24,040	401
	3	4	A	..	TP	180	121	4	11¾x15	276	135	1925	0	0	...	...	...	&C	0	S < 0.5%	No	0	...
	4	2	M	P	TP	840	564	6	16 x20	257	700	1929	5,090	1,194	...	...	3,581		128,595		No	1,351,153	1,132
	Plant					1,885	1,266				1,572			1,304	...	...	3,408		134,343			1,416,913	1,087
108	1	4	A	..	TP	600	403	6	17 x24	200	513	1927	2,527	...	...	...	...	CC	...	24°—26° B; 75 SSU @ 100 F	Yes	546,100	...
	2	4	A	..	TP	600	403	6	17 x24	200	513	1928	3,331	...	...	...	...	&	...	CC < 0.5%	Yes	698,800	...
	3	4	A	..	TP	675	453	6	17 x24	225	575	1930	5,027	...	...	...	...	BC	...	S < 0.5%	Yes	1,303,100	...
	Plant					1,875	1,259				1,601			2,385	...	300	2,895		229,970			2,548,000	1,070
837	1	4	A	..	CH*a*	750	504	4	23 x32	150	625	1922	7,500	2,831	...	...	1,987		229,798	...	No	1,763,770	623
	2	4	A	..	TP	450	302	6	16 x24	164	413	1918	824		...	...				...	No		
	3	4	A	..	TP	225	151	3	16 x24	164	200	1904	1,030	1,460	...	...	609	F	43,737	...	No	301,001	206
	4	4	A	..	TP	225	151	3	16 x24	164	200	1904	711		...	...				...	No		
	5	4	A	..	TP	225	151	3	16 x24	164	187	1906	562		...	...				...	No		
	Plant					1,875	1,259				1,625			4,291	...	...	1,517		273,535			2,064,771	481
1033	1	4	A	..	TP	500	336	4	18⅞x28¾	164	350	...	9	10	5	...	450		...		No	1,820	182
	2	4	A	..	TP	500	336	4	18⅞x28¾	164	350	...	339	157	123	...	1,080	S	...	22°+API	No	71,040	452
	3	4	A	..	TP	500	336	4	18⅞x28¾	164	350	...	605	328	199	...	922	&F	...		No	132,720	405
	4	4	A	..	TP	365	245	4	16¼x21	225	250	...	9	2	2	...	1,643		...	26°+API	No	970	485
	Plant					1,865	1,253				1,300			497	329	...	965		23,802			206,550	416
421	1	4	A	..	TP	800	537	8	17 x24	200	681	1930	5,428	1,535	260	...	2,828	CC	...	26°—28° API	No	1,808,300	1,177
	2	4	A	..	TP	1,000	671	8	17½x25	225	895	1933	4,644	1,728	1,228	...	2,686			1.0% S	No	1,991,300	1,153
	Plant					1,800	1,208				1,576			3,263	1,488	500	2,753		320,675			3,802,600	1,164
845	1	2	M	C	TP	360	242	6	14 x17	257	300	1927	4,384	...	...	...	...		...	30°—36° B	No	...	...
	2	2	M	C	TP	360	242	6	14 x17	257	300	1927	5,858	...	...	...	...	BC	...	S < 1.0%	No	...	...
	3	2	M	P	TP	1,050	705	7	16 x20	257	900	1931	955	...	...	...	...		...	Ash < 0.05%	No	...	...
	Plant					1,770	1,189				1,500			2,748	...	...	1,706		166,853			1,489,775	542

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 2, Continued)

Loading												Maintenance and Repairs									Attendance					
Factor (See Text)	Running Plant Capacity Factor (See Text)	Peak Load During Reported Period—Gross K.W.	B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used?	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc in Enforced Shutdown Time—Hours	No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
.4		520	60.3	58.4	A	No						......	......	......	......	......	Piston Rings	1	.....	......	365	7	2			60
.5		520	60.3	58.4	A	No						......	......	......	......	......	None	0	0	......	365	7	1			
5		520	60.3	58.4	A	No						......	......	......	......	......	None	0	0	......	365	7	1			
	21 6	520					D	90	130	N	N										365	3	1	69	4,000	
...		......	57.5	....	O	....						......	......	......	......	......	....	...	.	....	.		...			1149
...		.....	57 5	....	O	....						......	......	......	......	......	....	...	...	....			..			
	...	1,650					......	.....	......	....	...					......								37	..	
.8		400	74.6	85 6	W	No							0	0	0		P. Pin Bs.; Cp. P. Rs.;	....	.....	......						41
.4		500	75 3	80.1	W	No						568	0	0	0	0.24	P. C. Tube Parts; Fuel	....	.....	......	365	8	2			
.3		900	75.5	88.0	W	No							C	0	0		Oil Pu. Parts; H.P.	....	.....	......	.365	8	3			
	59.7	1,200					A	60	110	N	B						Air C. Coil			.	365	8	2	160	20	
.7		200	29.4	29.1	A	No								0	0		....	0	0	7						723
.5		200	29.4	29.1	A	No								0	0		Pu. Push Rods & Bush.	0	0	11	339	8	2			
7		460	46.0	43.8	O	Yes						—1,	501—	0	0	0.63	Pu. Push Rod & Bush.	0	0	90	339	8	1			
.9		720	57.5	58 7	O	Yes								0	0		1-Fuel Pump Nozzle	1	19	94	339	8	1			
	73 8	1,580					C	96	110	N	N										78	8	1	118	1,200	
2		520	57.5	59 2	O	Yes						......	......	......	......	......	1-Telescope Tube &	1	8	......	313	8	1			34
.5		520	57.5	59.2	O	Yes						......	......	......	......	......	Pocket; 2-Comp. Re-	0	0	......	341	8b	1			
.3		520	57.5	59.2	O	Yes						......	......	......	......	......	lief V.; Springs & Disks	0	0	......	72	8	1	275	770	
	60 2	800					B	......	......	L	B						for Comp. Valves									
2		110	75.0	54.6	A	No						0	0	0	0	0	....	0	0	......						79
		100	75.0	49.6	A	No						0	0	0	0	0	....	0	0	......						
.0		400	73.8	73.2	A	No						350	0	0	0	0.58	Bearings	0	0	......						
.6		325	74.0	69.0	W	No						150	0	0	0	0.29	Rings	0	0	......	365	8	3			
.8		400	73.8	73.2	A	No						689	0	0	0	1.15	Cylinders	0	0	......	365	8	2			
	64 8	900					B	85	96	N	N					0.55					365	8	2	150	360	
...		......	46 0	....	O	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			5
...		......	46.0	....	O	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			
...		.....	46 0	....	O	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			
	....	1,500					......	......	......	....	...					......								152	....	
..		......	29 4	....	A	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			6
...		......	69 8	....	A	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			
..		......	69 8	....	A	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			
...		.....	69 8	..	A	....						......	......	......	......	......	....	....	.....	......	.....	.....	....			
	93 5	1,490					......	......	......	....	...					. .								...	....	
.2		120	35.3	26 3	A	No											1-Cyl. Head; Scaveng-	0	.....	......						68
.3		200	35 3	29.2	A	No						——	—1,5	55—	——	0.76	ing Pump Valves;	2	.....	......	312	8	1n			
.5		320	53.6	45.6	O	Yes											Rings, Fuel Pumps	0	.....	......	312	8	1n			
.7		600	57.5	57.1	O	Yes												1	.....	......	312	8	1n			
	65 4	670					B-F	90	110	N	N										156	8	1n	.....	832	
.2		688	74.6	76.5	A	Yes						253	344	0	0	0.60	P. Rs.; Cp. Rs.; C.	2	7	146						133
0		688	74.6	76.5	A	Yes						253	344	0	0	0.60	Coil P. Rs ; C. Coil	1	3½	140	297	7⅔	2n			
	81 6	1,376					A	75	120	W	N					0.60					297	4⅓	1n	.....	10	
6		......	77.2	....	A	Yes						25	0	0	0	0.02	Valve Springs & Gaskets	0	0	322	365	8	1			806
																					313	8	3			
.1		270	75.9	61.1	A	Yes						38	0	0	0	0.02	Valve Springs & Gaskets	0	0	493	313	8a	2			
.5		630	69.6	54.8	O	Yes						763	0	0	0	0.64	Valve Springs; Gaskets;	20	532	361						
	69 9	910					A	60	80	N	B/F					0.41	1-Piston; Oil C. Pipes				313	8	1	166	1,850	
.0		425	72 2	69 3	A	Yes						0	0	0	0	0	None	0	0	0						29
.7		450	72.2	73.4	A	Yes						0	0	0	0	0	None	0	0	0						
.2		460	72.2	74 9	A	Yes						0	0	0	0	0	None	0	0	0						
	57 6	980					B	70	110	N	N										225	8	3½	154	20	
2		600c	53.6	48.9	O	Yes						191	75	0	0	0.14	Piston Rings; General	0	0	168	312	8	[illegible]			215
1		600c	53.6	48.9	O	Yes						191	75	0	0	0.14	Inspection	0	0	168	312	8a	[illegible]			
	78 9	1,200c					B	99	104	N	N					0.14					156	8	[illegible]	.....	2,150	
4		......	77.1	....	A	Yes						0	0	0	0	0	None	0	0	0						807
.1		150	73.7	45 1	A	Yes						0	0	0	0	0	None	0	0	0	365	6	2			
0		0	79.4	....	A	Yes						0	0	0	0	0	None	0	0	0	365	6	1			
1		500	53.6	47.5	O	Yes						0	0	0	0	0	None	0	0	0	365	6	1			
	47 5	500					C	70	100	N	N					0					365	6	1	112	2,950	
6		420	72.6	75.7	A	No							0	0	0		1-P. Pin; 6-Exh. V. & S	0	0	175						108
1		410	72.6	73.9	A	No						565	0	0	0	0 30	1-Vert.T.B & Gov Shft	0	0	175						
2		475	72 6	76.1	A	No							0	0	0		6-Exh. Valves & Seats;	1	4	171	354	8c	1			
	54 9	790					C	100	130	N	L						1-Fuel Pump Body				50	8	1	209	850	
6		......	74 5	....	W	No											(See gg9)	....	.....	......						837
		......	75.0	....	A	No											3-Cyl. Heads; 1-Liner	....	....	......						
5		......	75 0	....	A	No						2,859	3,164	3,402	473	5.28	None	....	.....	......						
		......	75 0	....	A	No											None	....	.....	......	365	8	2p			
		......	75.0	....	A	No											1-Cyl. Head	....	. ...	......	365	8	2p			
	47 1	600					A	80	126	N	F										365	8	2p	110	5	
2		280c	76.0	63.3	A	No							0	0	0		3-Exh. Manifolds	0	0	......						1033
4		310c	76.0	70.1	A	No							0	0	0		(See gg10)	0	0	..						
3		300c	76.0	67.9	A	No						592	0	0	0	0.32	1-Exh. M Gov. Shft.	0	0	....	.....	8	1n			
.0		150c	73.5	45.0	A	No							0	0	0		None [Oil Guard]	0	0	......	.....	8	3n			
	64 1	850c					B	......	......	N	N										....	8	2n	.....	3,800	
.0		......	72 7	....	A	Yes						216	24	0	0	0.30	Piston Rings	0	0	120	365	8	4			421
0		......	73.2	....	A	Yes						0	0	0	0	0		0	0	0	365	8	2			
	63 1	......					A	70	110	N	N					0.13					365	8	2	158	620	
.		200	35 3	29.2	A	No												....	.....	......	.....	8	1			845
.		200	35 3	29.2	A	No						——	—1,800—	——	——	1.02	Piston Rings	....	.....	......	.....	8	1			
		470	57.5	38.3	O	No												....	.....	......	.....	8	1			
..	47 3	470					B-F	70	90	N	N										.....	8	1	.....	1,050	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 3)

	Engine Data													Lubrication					Fuel				
Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
854	1	2	M	C	TP	360	242	6	14 x17	257	300	1928	132	......	......	......	......	BC	......	30°—36° B	No	......	......
	2	2	M	C	TP	360	242	6	14 x17	257	300	1928	355	......	......	......	......		......	S < 1.0%; Ash < 0.05%	No	......	......
	3	2	M	P	TP	1,050	705	7	16 x20	257	900	1931	5,372	......	......	......	......		......	BS&W < 0.3%	No	......	......
	Plant					1,770	1,189				1,500			1,377	......	......	4,222		200,464			2,177,480	1,582
158	1	2	A	P	CH	1,760	1,182	8	17 x23	257	1,500	1930	524	300	100	......	3,074	S&F	37,969	18°—22°API; 0° F Pour Pt.	No	343,172	1,144
212	1	4	A	..	TP	875	588	8	17½x24	200	671	1929	398	100	65	29	3,483	S	14,998	33° B; 42 SSU @ 210 F	No	168,200	1,682
	2	4	A	..	TP	875	588	8	17½x24	200	671	1929	412	98	57	28	3,679	&F	15,508	0.08% S;	No	169,000	1,725
	Plant					1,750	1,176				1,342			198	122	57	3,579		30,506	Delivered by Tank Truck		337,200	1,702
722	1	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1923	188	55	......	......	684	BC	2,241	32°—36° API	No	......	......
	2	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1923	191	43	......	......	1,332		3,560		No	......	......
	3	2	M	P	TP	840	564	6	16 x20	257	700	1929	1,348	345	......	......	3,282		52,727		No	......	......
	4	4	A	..	TP	365	245	4	16¼x21	225	330	1916	362	76	......	......	1,739		9,670		No	......	......
	Plant					1,705	1,145				1,450			519	......	......	2,619		68,198			774,780	1,493
805	1	2	M	P	TP	840	564	6	16 x20	257	700	1928	16	0	0	......	......	BC	519	28°—30° API	No	4,230	......
	2	2	M	P	TP	840	564	6	16 x20	257	700	1929	13	0	0	......	......	&C	435	S < 0.5%	No	3,640	......
	Plant					1,680	1,128				1,400			0	0	......	......		954			7,870	......
18	1	2	M	C	CH	450	302	5	15½x16	275	......	1922	465	......	......	......	......	......	......	......	...	......	......
	2	4	A	..	TP	600	403	6	17 x25	200	......	1926	4,763	......	......	......	......	......	......	......	...	......	......
	3	4	A	..	TP	600	403	6	17 x25	200	......	1928	3,955	......	......	......	......	......	......	......	...	......	......
	Plant					1,650	1,108				......			2,129	......	......	2,552		208,390			2,205,070	1,035
88	1	4	A	..	TP	285	191	3	16½x24	200	240	1920	4,894	......	......	......	......	CC	53,790	32°—36° API;	No	555,650	......
	2	4	A	..	TP	285	191	3	16½x24	200	240	1920	2,983	......	......	......	......	&S	35,270	42 SSU @ 100 F;	No	332,160	......
	3	4	A	..	TP	300	202	3	16½x24	200	188	1925	3,767	......	......	......	......	&F	46,530	0.35% S; 0.01% Ash	No	477,800	......
	4	2	A	P	TP	750	504	5	14¾x21	257	650	1932	4,188	......	......	......	......		123,028		No	1,167,300	......
	Plant					1,620	1,088				1,318			2,289	1,338	300	2,846		258,618			2,532,910	1,106
8	1	4	A	..	TP	400	269	4	16½x24	200	350	1921	4,497	......	......		......	CC&F	......	26°—34° API	No	463,890	......
	2	4	A	..	TP	560	376	3	22½x22½	225	500	1922	82	......	......		......	CC	......		No	12,350	......
	3	4	A	..	TP	600	403	6	17 x25	200	500	1926	4,399	......	......		......	CC	......		No	1,078,190	......
	Plant					1,560	1,048				1,350			1,609	......	......	2,787		159,418			1,554,430	965
406	1	2	M	P	TP	600	403	4	16 x20	257	500	1930	2,104	264	......	0	4,781	BC	......	32°—36° API; 1.0% S	No	512,600	1,941
	2	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1923	3,592	660	......	0	1,632	C	......	0.25% Ash; 0.25% BS&W	No	343,000	520
	3	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1922	3,336	672	......	0	1,488	C	......		No	313,230	466
	4	2	M	C	TP	360	242	6	14 x17	257	300	1925	3,872	516	......	0	2,701	C	......		No	420,410	814
	Plant					1,560	1,049				1,300			2,112	......	0	2,241		189,211			1,589,240	753
10	1	4	A	..	TP	750	504	4	22 x29½	166⅔	625	1924	5,648	2,118	816	0	2,000	CC	174,723	27° API; 40 SSU @ 100 F;	No	1,923,300	908
	2	2	A	P	CH*a*	750	504	4	17 x27	176	625	1925	551	294	169	0	1,406		14,583	0.5% S; 1.5% CC;	No	156,920	534
	Plant					1,500	1,008				1,250		6,199	2,412	985	0	1,928		189,306	0.004% Ash Delivered by Tank Wagon	No	2,080,220	862
47	1	2	M	P	TP	1,500	1.007	5	19½x27	240	1,250	1932	4,550	1,833	......	......	3,722	BC&S	254,353	30°—36° B; S < 1.0% Ash <0.05%; BS&W<0.3%	No	3,021,340	1,647
1154	1	4	A	..	TP	750	504	6	17½x24½	225	750	1931	4,524	......	......	0	......	BC	121,861	32°—34° API	No	1,255,900	......
	2	4	A	..	TP	750	504	6	17½x24½	225	750	1931	4,445	......	......	0	......	&S	119,912		No	1,200,000	......
	Plant					1,500	1,008				1,500			746	706	0	9,020		241,773			2,455,900	3,290
289	1	4	A	..	TP	250	168	4	13¾x17½	257	210	1920	5,478	651	297	0	2,103	BC	56,160	26°—30° API	No	644,970	991
	2	4	A	..	TP	250	168	4	13¾x17½	257	210	1920	5,462	908	316	0	1,503		55,872		No	640,470	706
	3	4	A	..	TP	365	245	4	16¼x21	225	300	1915	4,529	891	279	0	1,856		62,803		No	743,790	834
	4	4	A	..	TP	600	403	6	16¼x23	225	512	1927	2,291	697	234	0	1,972		59,254		No	717,800	1,029
	Plant					1,465	984				1,232			3,147	1,126	0	1,830		234,089			2,747,030*h*	873*h*
496	1	4	A	..	TP	400	269	4	16½x24½	200	340	1925	3,674	154	117	0	9,540	CC	41,693	32°—36° API	No	437,625	2,830
	2	4	A	..	TP	300	201	3	16½x24½	200	250	1925	4,601	341	117	0	4,047	BC	40,463	S < 1.0%	No	390,550	1,145
	3	4	A	..	TP	750	504	6	17½x24½	225	650	1928	1,569	134	121	0	8,780	S&C	37,095		No	373,000	2,783
	Plant					1,450	974				1,240			629	355	0	6,400		119,251			1,201,175	1,910
850	1	4	A	..	TP	600	403	6	17 x25	200	500	1926	8,214	......	......	......	......	BC	......	30°—36° B; S — 1.0%	No	......	......
	2	2	M	P	TP	840	564	6	16 x20	257	700	1928	2,996	......	......	......	......		......	Ash <0.05%; BS&W<0.3%	No	......	......
	Plant					1,440	967				1,200			3,220	......	......	2,311		280,723			2,844,460	884
70	1	2	M	P	TP	560	376	4	16 x20	257	470	1928	4,408	......	......	......	......	CC	......	32°—36° API	No	864,783	......
	2	2	M	P	TP	560	376	4	16 x20	257	470	1928	4,487	......	......	......	......	S&F	......		No	869,250	......
	3	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1923	496	......	......	......	......		......		No	57,850	......
	Plant					1,420	954				1,190			2,150	......	55	2,385		198,000			1,791,883	834
849	1	2	M	C	TP	360	242	6	14 x17	257	300	1928	3,473	......	......	......	......	BC	......	30°—36° B; S < 1.0%	No	......	......
	2	2	M	P	TP	1,050	705	7	16 x20	257	900	1931	3,684	......	......	......	......		......	Ash <0.05%; BS&W<0.3%	No	......	......
	Plant					1,410	947				1,200			2,618	......	......	1,955		243,220			2,516,180	961
154	1	4	A	..	TP	600	403	6	17 x24	200	......	1927	1,688	......	......	......	......	......	......	......	..	......	......
	2	4	A	..	TP	400	269	4	17 x24	200	......	1926	2,921	......	......	......	......	......	......	......	..	......	......
	3	4	A	..	TP	400	269	4	17 x24	200	......	1925	1,659	......	......	......	......	......	......	......	..	......	......
	Plant					1,400	941				......			904	......	......	3,150		121,977			1,513,170	1,674
163	1	4	M	..	TP	400	269	4	17¾x22	225	343	1924	1,225	120	......	0	4,083	BC	12,045	37.7° API; 45 SSU @ 100 F	No	123,600	1,030
	2	4	M	..	TP	400	269	4	17¾x22	225	343	1927	4,601	440	......	120	4,180		62,837	0.2% S; 0.002% Ash	No	653,700	1,485
	3	4	M		TP	600	403	6	17¾x22	225	625	1929	4,110	522	......	120	4,724		95,041	BS&W—Nil. Delivered	No	994,425	1,904
	Plant					1,400	941				1,311			1,082	......	240	4,434		169,923	by Refinery Pipe Line		1,771,725	1,635
198	1	2	M	P	TP	1,400	941	8	16 x20	300	1,392	1932	5,525	2,517	......	0	3,073	BC	324,674	35.4°API; 41.3 SSU @ 100F; Ash-Nil; 0.29%S; 0.01%CC; BS&W—Trace	No	3,666,420	1,456
517	1	4	A		TP	625*f*	420	5	17½x25	225	625	1930	1,237	816	270	0	3,245	CC	64,340	28°—30° API; 0.5% S	No	542,830	665
	2	4	M	..	TP	750	504	6	17 x25	225	625	1932	4,523	482	274	0	7,040		63,400	0.1% CC	No	579,730	1,203
	Plant					1,375	924				1,250			1,298	544	0	4,654		127,740			1,122,560	865
888	1	4	A	..	TP	300	202	3	17 x24	200	250	1925	1,686	......	......	......	......	CC&F	......	33.9° B; 0.338% S;	No	158,650	......
	2	4	A	..	TP	400	269	4	17 x24	200	375	1925	3,520	......	......	......	......	CC&F	......	CC and BS&W—Nil	No	495,900	......
	3	4	A	..	TP	675	453	6	17 x24	225	575	1931	7,017	......	......	......	......	CC	......	Fuel by Barge	No	1,671,940	......
	Plant					1,375	924				1,200			1,378	......	......	4,825		228,830			2,326,490	1,687

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 3, Continued)

Loading: Running Engine Capacity Factor (See Text)	Loading: Running Plant Capacity Factor (See Text)	Loading: Peak Load During Reported Period—Gross K W	Loading: B.M.E.P. at Rated B.H.P.—Lbs per Sq In.	Loading: B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used?	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Maintenance and Repairs: Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	Attendance: No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
....		200	35.3	29.2	A	No											....	....	....	......	312	8	1q			854
....		200	35.3	29.2	A	No							306			0.17	....	....	....	......	312	8	1q			
....		700	57.5	57.1	O	No											....	....	....	......	312	8	1q			
	55.8	880					......	70	80	N	N										159	8	1q	236	900	
5.4	55.4	1,000	64.9	54.9	O	Yes	B-Fr	56r/90	100r/	N	B/F															
							D-F		120			23s	0	0	0	0.01s	Comp. Valves & Springs	3	1	......	365	8	1	109	1,612	158
1 9		570	75 1	72 8	A	No						697	0	0	0	-	1-Cyl.; 1-Liner; Bear-	0	0	.....	365	8	1n			212
9.7		560	75 1	71.5	A	No							0	0	0	0.40	ings for Fuel Pump;	0	0	......	365	8	2n			
	70.8	570					A-F	53	125	N	N						Gaskets				365	8	1n	.....	585	
....		120	29.4	26.3	A	No								0	0		Piston Rings; Fuel Oil	0	0	0						722
....		180	29.4	26.2	A	No								0	0	0.53	Pumps; Air Valves	0	0	9	339	8	2			
....		600	53.6	57.0	O	Yes						896		0	0			0	0	243	339	8	1			
....		220	73.8	66.3	A	No								0	0			0	0	33	339	8	1			
	84.9	1,100					C	95	109	N	N										78	8	1	62	1,250	
6.9		380	53.6	36.1	O	Yes						0	0	0	0	0	None	0	0	0	365	10	1			805
9.6		380	53.6	36.1	O	Yes						0	0	0	0	0	None	0	0	0	365	7	1			
	48.1	380					C	65	90	N	N										365	7	1	1	2,533	
.....		......	44.3	....	A	....						......	......	......	......	......	....	...	...	...	....	...	...			18
....		......	69 8	....	A	....						......	......	......	......	......	....	...	...	...	....	...	...			
....		......	69 8	....	A	....						......	......	......	......	......	....	...	...	...	....	...	...			
	60.4	940					......	......	......	....	....					.....								212	...	
9.4		200	73.3	76.8	A	No							0	0	0		Piston Rings; Valves;	0	0	......						88
8.3		200	73.3	76.8	A	No						237	0	0	0	0.15	Packing; 1-Comp.	0	0	......	355	8	3			
2.8		200	77.1	76.8	A	No							0	0	0		Bearing; Gaskets	0	0	......	355	8	2			
5.3		520	64.3	66.4	O	Yes							0	0	0			0	0	......	355	8	2			
	57.9	675					A	65	100	N	N										70	8	1	121	821	
8.3		......	77.2	....	A	No						1,330	0	0	0	3.33	2-P.; 1-H.; R Cam.Shft.	0	0	......	.....	8	3			8
0.1		......	73.4	....	O	No						0	0	0	0	0	None [Grs.	0	0	......	.....	8	1			
0.8		......	69.8	....	A	No						280	0	0	0	0.47	Rings	0	0	......	.....	8	1			
	51.6	......					B-F	75	110	B	N					1.03					.....	8	1	.....	1,160	
0.5		400	57.5	57.2	O	Yes						13	0	0	0	0.02	No Major Parts	0	0	56						406
7.3		155	29.4	22.7	A	No						112	0	0	0	0.37	Rings	0	0	56						
6.5		155	29.4	22.7	A	No						121	0	0	0	0.40	Rings	0	0	56	365	8	1			
4.9		185	35.3	27.1	A	No						116	0	0	0	0.32	Rings	0	0	56	365	8	1			
	50.0	425					D	80	120	N	N					0.23					365	8	1	169	1,310	
7.6		440	79.5	69.4	W	No						811	168	0	0	1.31	Injection, Inlet & Exh.	3	4½	......						10
5.5		440	68.8	60.1	W	Yes						159	395	0	0	0.74	Valve Parts; Piston	0	0	......	274	8b	2n			
	66.6	440					A	72	110	N	L					1.02	Rings; Msc.				273	8	2n	.....	21	
5.9	65 9	1,050	61.4	64.0	O	Yes	B	70	90	N	N		775			0.52	....	....	....	......	....	8c	1 n	.....	3,400	47
.1		......	74.7	....	A	Yes						291	0	0	0	0.19	Piston Rings; Gaskets;	1	½	16	315	8	3			1154
.6		......	74.7	....	A	Yes							0	0	0		Springs	0	0	16						
	54.3	750					A	44	110	N	B										315	8b	2	107	1,450	
1		......	74.1	....	A	Yes							0	0	0		1-Piston; 1-Cyl. Head;	0	0	120						289
8		......	74.1	....	A	Yes						1,413	0	0	0	0.97	1-Set of Timing Gears;	0	0	168						
0		......	73.8	....	A	Yes							0	0	0		1-Main Thrust Bearing	0	0	192	365	8	2			
.8		......	73.8	....	A	Yes							0	0	0			0	0	192	365	8	3			
	71.0	820					A	50	105	F	B										365	8	2	128	1,670	
.3		280	75.4	78 5	A	Yes						0	0	0	0	0	....	0	0	......						496
2		220	75 4	82.6	A	Yes						0	326	0	0	1.09	....	0	0	......	365	10	2			
.2		520	74.4	76.8	A	Yes						105	55	0	0	0.21	H.P. Cp. Coil; Cp. V.	0	0	......	365	10	1			
	44.4	650					D	100	122	F	N					0.34					365	10	1	76	1,200	
...		......	69.8	....	A	No							1,676				....	....	....	....	.....					850
...		......	53.6	....	O	No										1.16	....	....	....	....	.....					
	56 9	980					A	55	70	N	B										.....	8c	1	.....	2,385	
2		360	53 6	51.4	O	Yes						0	0	0	0	0	None	3	1	......						70
5		340	53.6	48.5	O	Yes						126	0	0	0	0.23	1-Cyl. Head	0	0	......	365	8	2			
.8		170	29 4	24.7	A	No						0	0	0	0	0	None	0	0	......	365	8	1			
	52.0	490					A	......	80	N	N					0.09					365	8	1	137	1,330	
...		220	35 3	32.1	A	No							1,564				....	....	....	....	.....					849
...		730	57.5	59.5	O	No										1.11	....	....	....	....	.....					
	73 2	950					A	55	70	N	N										....	8c	1n	.....	3,200	
...		......	72 7	...	A	....						......	......	......	......	......	....	....	....	....	.....	...	...			154
...		......	72 7	....	A	....						......	......	......	......	......	....	....	....	....	.....	...	...			
...		......	72.7	....	A	....						......	......	......	......	......	....	....	....	....	.....	...	...			
	79.2	570					......	......	......	.....	.....					.....								142	.....	
.5		270	64.7	64.9	A	No						......	......	......	......	......	Piston Rings	....	....	......	184	a	1n			163
.8		290	64 7	69 7	A	No						......	......	......	......	......	....	....	....	......	300	....	1n			
.0		440	64 7	70 6	A	No						......	......	......	......	......	Piston Rings	....	....	.....	185	....	1n			
	55.0	1,000					B	53	76	N	N					......					542	....	3n	.....	1,020	
																	1-Scavng. Air Piston; 2				348	8	2n			
1.6	70.6	1,000	57 5	61.1	O	Yes	D	107	113	N	N	......	......	......	......	......	Scav. Cyl. Heads; All	3	202	28	348	8	1n	.....	1,109	198
																	at Mfgr's Expense				51	8	1n			
.5		375	73.2	65.4	A	Yes						65	0	0	0	0.10	(See gg 11)	0	0	215						517
.4		375	77.6	57.8	A	Yes						10	0	0	0	0 01	4-Spray Valve Springs	0	0	120	353	8b	1	118	1,100	
	27.7	375					D-F	85	115	N	B					0.06					36	8	1			
6		160u	72 7	57 6	A	No								0	0		Rb. 3 Cr. Pin B.;9-P.R.	0	0	416u						888
4		260u	72 7	70 3	A	No						4,605	1,075	0	0	4.13	(See gg 12)	1	144	584u	365	8	2			
6		460u	72.7	73 2	A	No								0	0		(See gg 13)	2	241	1,047u	365	8	2			
	52 1	840					A	54	......	N	N										365	8	2	129	10	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 4)

Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
	Engine Data													**Lubrication**					**Fuel**				
725	1	4	A	..	TP	600	403	6	17 x25	200	500	1926	5,682	....	1,103	....	....	BC S& C	....	32°—36° API; 0.5% S	No	....	.....
	2	4	A	..	TP	400	269	4	17 x25	200	337	1925	3,575	....	476	....	....		....		No	....	.....
	3	2	M	C	TP	200 m	134	4	14 x17	257	170	1924	2,500	....	330	....	....		....		No	....	.....
	4	2	M	C	TP	110 m	74	2	14 x17½	257	100	1923	0	....	0	....	....		....		No	....	.....
	Plant					1,310	880				1,107			2,941	1,909	100	1,815		189,733			2,071,200	704
886	1	2	M	C	TP	120	81	2	14 x17	257	85	1927	2,018	....	.....	.....	....	BC, S &F	....	....	No	70,662	.....
	2	2	M	C	TP	200 m	134	4	14 x17	257	170	1925	2,540	....	.....	.....	....		....	....	No	177,461	.....
	3	2	M	C	TP	360	242	6	14 x17	257	300	1929	2,199	....	.....	.....	....		....	....	No	222,478	.....
	4	4	A	..	TP	625	420	5	17½x25	225	535	1931	2,881	....	.....	.....	....		....	....	No	442,724	.....
	Plant					1,305	877				1,090			2,150	.....	.....	1,555		127,740			913,325	424
13	1	4	A	..	TP	275	185	4	13½x19½	257	219	1923	6,509	1,177	871	306	1,520	CC &S	75,450	30° API; 0.28% S; 0.02% CC Ash and BS&W—Nil	No	756,500	643
	2	4	A	..	TP	200	134	3	13½x19½	257	156	1923	2,660	451	339	386	1,180		19,140		No	210,700	467
	3	4	A	..	TP	750	504	4	23 x29½	164	625	1925	1,480	745	396	55	1,490		40,970		No	333,500	448
	Plant					1,225	823				1,000			2,373	1,606	747	1,446		135,560			1,300,700h	548h
16	1	4	A	..	TP	600	403	6	17 x25	200	512	1927	213	....	.....	.....	....	BC & CC	....	28°—30° API	No	83,760	.....
	2	2	M	C	TP	240	161	4	14 x17	257	200	1925	87	....	.....	.....	....		....		No	11,536	.....
	3	2	M	C	TP	360	242	6	14 x17	257	300	1925	89	....	.....	.....	....		....		No	17,840	.....
	Plant					1,200	806				1,012			296	.....	50	611		10,619			113,136	382
17	1	4	A	..	TP	600	403	6	17 x25	200	....	1926	4,274	....	.....	.....	....	....	....	....	.....	....	.....
	2	4	A	..	TP	600	403	6	17 x25	200	....	1926	4,095	....	.....	.....	....	....	....	....	.....	....	.....
	Plant					1,200	806				....			1,472	.....	.....	3,411		192,906			1,997,800	1,357
846	1	2	M	C	TP	360	242	6	14 x17	257	300	1927	5,006	....	.....	.....	....	BC	....	30°—36° B; 1.0% S; Ash <0.05%; BS&W<0.3%	No	....	.....
	2	2	M	P	TP	840	564	6	16 x20	257	700	1929	2,641	....	.....	.....	....		....		No	....	.....
	Plant					1,200	806				1,000			1,802	.....	.....	2,231		160,448			1,668,900	927
889	1	2	M	P	TP	1,200	806	8	16 x20	257	900	1931	4,460	1,283	.....	.....	4,165	BC	222,613	30°—36°B; S< 1.0%; Ash <0.05%; BS&W<0.3%	No	2,461,720	1,918
980	1	4	A	..	TP	750	504	6	17½x24½	225	625	1929	3,674	....	462	0	....	CC	....	25.4° API; 0.5% S; 1.14% CC; 0.002% Ash; 0.1% BS&W	No	....	.....
	2	4	A	..	TP	450	302	4	17 x24½	225	375	1927	5,271	....	540	0	....		....		No	....	.....
	Plant					1,200	806				1,000			1,713	1,002	0	2,993		168,650			1,757,700	1,026
1083	1	2	M	P	TP	1,200	806	8	16 x20	257	1,042	1931	4,548	1,890	.....	170	2,886	BC	201,872	26°—30° API	No	2,695,050	1,426
330	1	4	A	.	TP	625t	420	5	17½x25	225	450	1930	2,435	....	.....	.....	....	BC	....	32°—36° API	No	429,350	.....
	2	2	M	C	TP	240	161	4	14 x17	257	200	1928	4,745	....	.....	.....	....		....		No	215,350	.....
	3	2	M	C	TP	100 m	67	2	14 x17	257	70	1917	2,555	....	.....	.....	....		....		No	91,250	.....
	4	2	M	C	TP	200 m	134	4	14 x17	257	170	1919	4,380	....	.....	.....	....		....		No	208,520	.....
	Plant					1,165	782				890			2,747	.....	.....	1,380		122,255			944,470	344
878	1	2	M	P	TP	560	376	4	16 x20	257	470	1929	4,960	....	.....	.....	....	BC	....	28°—30° API; Not over 220 SSU @ 100 F; S <0.5%; BS&W<1.0%	No	1,368,600	.....
	2	2	M	C	TP	200 m	134	4	14 x17	257	170	1919	69	....	.....	.....	....		....		No	6,280	.....
	3	4	A	..	TP	400	400	4	17 x25	200	337	1924	4,201	....	.....	.....	....		....		No	884,000	.....
	Plant					1,160	779				977			2,221	.....	.....	2,013		223,376			2,258,880	1,017
616	1	4	A	.	TP	300	202	3	16½x23	200	250	1923	5,774	857	.....	0	2,021	CC &F	66,947	20°—22° API	No	812,380	948
	2	2	M	C	TP	100 m	67	2	14 x17	257	75	1920	100	25	.....	0	400		650		No	5,000u	200
	3	4	A	..	TP	750	504	4	23 x32	150	657	1925	2,994	720	.....	0	3,119		68,850		No	764,420	1,062
	Plant					1,150	773				982			1,602	.....	0	2,489		136,447			1,581,800	987
887	1	2	M	C	TP	150 m	101	3	14 x17	257	125	1922	0	....	.....	.....	....	BC &C	....	....	No	0	.....
	2	2	A	P	CH	440	295	4	15 x20	225	375	1930	58	....	.....	.....	....		....	....	No	8,050	.....
	3	4	M	..	TP	550	369	5	17 x24	225	438	1928	8,702	....	.....	.....	....		....	....	No	1,154,870	.....
	Plant					1,140	765				938			1,090	.....	.....	4,411		139,521			1,162,920	1,067
78	1	4	M	..	TP	400	269	4	17 x24	225	375	1928	6,691	831	45	162	3,220	CC	87,787	30.9° API	No	710,200	855
	2	4	M	..	TP	660	443	6	17 x24	240	625	1930	5,676	953	48	268	3,930		154,912		No	1,624,924	1,705
	Plant					1,060	712				1,000			1,784	93	430	3,595		242,699			2,335,124	1,308
519	1	2	M	C	TP	200 m	134	4	14 x17	257	170	1925	1,900	....	.....	0	....	S C&F	....	32°—36° API	No	....	.....
	2	2	M	C	TP	300 m	202	6	14 x17	257	250	1922	807	....	.....	0	....		....		No	....	.....
	3	2	M	P	TP	560	376	4	16 x20	257	470	1929	6,552	....	.....	0	....		....		No	....	.....
	Plant					1,060	712				890			1,644	.....	0	2,609		166,500			1,668,238	1,014
203	1	2	M	P	TP	525	352	5	14 x17	300	447	1931	4,260	....	.....	0	....	CC	....	....	No	790,700	.....
	2	2	M	P	TP	525	352	5	14 x17	300	447	1931	4,548	....	.....	0	....		....	....	No	795,700	.....
	Plant					1,050	704				894			2,560	.....	0	1,806		157,693			1,586,400	619
259	1	2	M	C	TP	210	141	3	14 x17	300	170	1931	6,498	646	.....	.....	2,111	BC &F	45,390	....	No	523,376	810
	2	2	M	C	TP	360	242	6	14 x17	257	300	1926	1,367	190	.....	.....	2,590		20,220	....	No	148,949	784
	3	2	M	P	TP	480	322	4	16 x20	257	400	1928	895	170	.....	.....	2,526		17,130	....	No	138,040	812
	Plant					1,050	705				870			1,006	.....	.....	2,272		82,740			810,365	805
847	1	2	M	P	TP	1,050	705	7	16 x20	257	900	1931	6,303	1,694	.....	.....	3,905	BC	248,040	30°—36° B; S <1.0% Ash <0.05%; BS&W<0.3%	No	2,815,400	1,662
1144	1	2	M	C	TP	210	141	3	14 x17	300	167	1931	5,320	800	.....	0	1,396	BC C&F	37,907	28°—32° B	No	440,100	550
	2	2	M	C	TP	420	282	6	14 x17	300	353	1931	3,564	894	.....	0	1,674		54,233		No	644,500	721
	3	2	M	C	TP	420	282	6	14 x17	300	353	1931	3,533	933	.....	0	1,590		54,425		No	645,700	692
	Plant					1,050	705				873			2,627	.....	0	1,559		146,565			1,730,300	659
56	1	4	A	..	TP	500	336	5	17 x24½	200	438	1926	2,872	478	436	0	3,004	CC	57,326	28°—32° API; 50 SSU @ 100 F; 0.01% S; 0.01% CC; 0.0008%Ash; BS&W-Trace	No	668,900	1,398
	2	4	A	..	TP	500	336	5	17 x24½	200	438	1929	2,853	493	452	0	2,893		54,422		No	682,299	1,383
	Plant					1,000	672				876			971	888	0	2,945		111,748			1,351,199	1,391
801	1	2	A	P	CH	1,000	671	4	20¾x26	180	937	1927	7,329	2,150	.....	0	3,409	BC&S	366,030	22°—26° API; 1.0% S	Yes	4,428,200	2,060
1061	1	2	M	P	TP	980	658	7	16 x20	257	975	1930	4,104	1,989	.....	60	2,020	BC&S	196,725	35.2° API; 41 SSU @ 100F 0.282% S; 0.01% CC; Ash—Nil; BS&W—Trace	No	2,256,400	1,135
53	1	2	M	C	TP	200 m	134	4	14 x17	257	170	1923	118	51	.....	5	463	S &C	....	23.5° API	No	13,350	262
	2	2	M	C	TP	300 m	202	6	14 x17	257	250	1925	318	153	.....	5	623		....		No	48,610	317
	3	4	A	.	TP	400	269	4	16½x23	225	338	1925v	7,350	1,194	334	60	2,460		....		No	1,306,940	1,092
	Plant					900	605				758			1,398	.....	70	2,185		125,025			1,368,900	979

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 4, Continued)

Loading												Maintenance and Repairs									Attendance					
Factor (See Text)	Running Plant Capacity Factor (See Text)	Peak Load During Reported Period—Gross K.W.	B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Cost of Engine Regular Upkeep—Dollars		Cost of Repairs for Engine Accidents—Dollars		Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
												Material	Extra Labor	Material	Extra Labor											
...		325	69.8	56.3	A	No												1	65	0						725
...		205	69.8	53.2	A	No						80					Spray Valve Parts	0	0	0	313	8	1			
...		109	29.4	23.9	A	No										0.06		1	5	0	313	8	1			
...		0	31.5	....	A	No												0	0	0	313	8	1			
	57.8	630					D-F	90	110	F	N										156	8	1	230	572	
.3		69	35 3	30.1	A	No											....	0	0	0						886
.1		138	29.4	30.3	A	No						2,386				1.83	....	0	0	120	313	8	1			
.9		193	35.3	28.2	A	No											....	0	0	600	313	8	1			
.6		307	73.2	53.5	A	No											....	0	0	0	313	8	1			
	40.7	307					D	......	......	N	N										156	8	1	99	2,970	
.8		180	75.8	73.8	A	No						101	0	0	0	0.37	Piston Rings & Piston	0	0	60	340	8	1			13
1		140	73.5	76 8	A	No						103	0	0	0	0.52	Pin Bearings	0	0	35	340	8	1			
.7		375	73.8	54.9	W	No						225	0	0	0	0.30		0	0	120	340	8	1			
	56.4	375					A	80	115	N	L					0.35					75	8	1	132	70	
.7		420	69 8	72 8	A	Yes						0	0	420	140	0 93	Exh. Manifold Failure	1	316	0						16
.4		160	35 3	35 1	A	Yes						0	0	312	95	1.70	Piston Rod Failure	1	288	0						
.8		240	35.3	35.0	A	Yes						0	0	0	0	0	None	0	0	0	.....	8	1n			
	93.3	810					B-F	90	110	N	N					0.81					.....	8	1n	.....	1,100	
...		......	69.8	....	A	....						......	......	......	......	......	....	....	....	....	....	....	....			17
...		......	69.8	....	A	....						......	......	......	......	......	....	....	....	....	....	..	.			
	59.2	870					......	......	......	....	....					......								189	.....	
...		200	35 3	29.2	A	No						536					....	....	....	....	....					846
...		560	53 6	53 2	O	No										0 45	....	....	....	....	....					
	61.8	760					B	70	90	N	N										.....	8c	1q	.....	2,300	
.5	68.5	770	57.5	54.9	O	No	A	55	80	N	N	1,465				1 22	....	....	....	......	.....	8c	1n	.....	4,100	889
...		510	74.6	75.5	A	No						197	0	0	0	0.26	Piston Rings	0	0	......						980
...		320	71.2	75.5	A	No						132	0	0	0	0.29		0	0	......	307	8b	2			
	51.0	510					A	70	110	N	N					0.27					187	8	2	97	15	
.5	73 5	800	57.5	57.1	O	Yes	B-F	90	110	N	F	800	330	0	0	0.94	Spray V. P. and Sle.; 1-Cracked Cyl.	0	0	336.	...	8c	1n	.....	1,100	1083
.0		300	73 2	52.2	A	Yes								0	0		None	0	0	......						330
.2		170	35 3	37.3	A	No						553	184	0	0	0.63	Piston Rings & Gaskets	0	0	......	313	8	1½			
.3		50	29 4	21 9	A	No								0	0		Piston Rings & Gaskets	0	0	......	313	8	1			
.5		120	29.4	26 3	A	No								0	0		Piston Rings & Gaskets	0	0	......	313	8	1			
	37.1	350					B	50	95	N	N										156	8	1	87	4,551	
.4		400	53.6	57.0	O	Yes											5 Piston Rings	6	.....	......	288	10	1			878
.0		120	29 4	26.3	A	No						1,273				1.10	None	0	0	......	288	10	2			
.2		275	69.8	71.4	A	No											12 P. R.; 1 C. B.	2	.....	......	288	10	1			
	75.3	700					D-F	85	110	N	N										77	8b	1	139	2,163	
.7		200	77.2	76.4	A	Noe							64	0	0			0	0	......						616
.6		50	29.4	21.9	A	No						911	0	0	0	0.91	Piston Rings	0	0	.....	365	8	3			
.7		500	74.5	74.0	W	Noe							64	0	0			0	0	.....	365	8	1			
	59.0	500					B	90	120	N	F										365	8	1	98	15	
...		0	29.4	....	A	No											....	0	0	0	313	8	1			887
1		180	54.7	33.4	W	Yes						-63				0.06	....	0	0	15	313	8	1			
0		340	71.1	65.5	A	Yes											....	2	2	56	313	8	1			
	36 0	340					D-F	......	......	N	N										156	8	1	124	4,082	
.5		......	64.6	....	A	Yes						124	444	0	0	1.42	....	0	0	......	....	....	....			78
.6		......	66.7	....	A	Yes						295	628	0	0	1.40	....	1	2	......	....	....	....			
	54.2	835					A	72	95	N	N					1.41					365	6c	1	256	172	
...		135	29.4	29.5	A	No						380	0	0	0	1.90	Rings and Bearings	0	0	320						519
...		200	29.4	29.1	A	No						227	0	0	0	0.76	Rings	1	½	120	365	10	2n			
...		390	53 6	55.5	O	Yes						3,418	0	0	0	6.10	4 Pistons; 4 Cyls. Bored; Main Bearings; Rings	0	0	690	365	10	1½n			
	57.9	390					A	70	80	N	N					3.80					365	10	1n	.....	500	
7		425	52.9	63.9	O	Yes						0	27	0	0	0.03	None	0	0	168	365	8	1			203
7		425	52.9	63.9	O	Yes						0		0	0		None	0	0	120	365	8	1			
	51.1	450					D-F	103	107	N	N										365	8	1	167	1,100	
.1		130	35.3	32.6	A	No						0	0	0	0	0	1-Piston; 1-Cyl. Head;	....	.....	29						259
.0		175	35 3	25.5	A	No						14	11	297	16	0.94	Bearings, Gaskets; etc.	....	.....	338	365	8	1			
.9		200	46.0	28.6	O	No						82	0	0	0	0.17		....	.....	139	365	8	1			
	52.8	210					C	100	110	N	N					0.40					365	8	1	84	3,467	
.4	63.4	700	57.5	57.1	O	No	B	70	90	N	N	1,077				1.03	....	....	....	......	.....	8c	1	.....	2,000	847
.7		125	35 3	31.3	A	No						......	......	......	......	......	....	0	0	20	308	8	1			1144
.1		250	35.3	31.3	A	No						......	......	......	......	......	....	0	0	30	309	8	1			
.8		250	35.3	31.3	A	No						......	......	......	......	......	1-Cylinder..........	1	2	28	308	8	1			
	62 9	515					C	100	120	N	N										200	8	1	183	800	
.4		400	71.2	84.8	A	Yes						......	......	......	......	......	1-Connecting Rod Brg.	0	0	336						56
.2		400	71.2	84.8	A	Yes						......	......	......	......	......	Rings & Cooling Coil	0	0	336	180	8	1			
	70 3	800					A	60	105	N	L						2-Rings				180	8	1	435	850	
.0	90.0	700	62.5	65.2	W	Yes	A	......	......	N	N	2,062	348	0	0	2.41	Cyl. Liners; Oil Filter; Piston Rods; Piston Heads; Rings	18	141	582	313 313 156	8 8a 8	1½ 1 1	420	591	801
.5	83.5	700	53.6	57.0	O	No	D	101	106	N	N	......	......	......	......	......	Only Minor Parts; Incl. Cam Shaft Previously Installed	3	27½	166	348 348 51	8 8 8	2n 1n 1n	.....	.....	1061
5		160c	29 4	35.1	A	No						0	0	0	0	0	None	0	0	0	321	8	1			53
7		200c	29 4	29 1	A	No						14	0	0	0	0.05	None	1	2	12	321	8	1			
1		240c	73.8	65 9	A	No						1,933	567	0	0	6.25	Rebab. Main Bearings	13	46	1,364	322	8	1			
	66.7	500c					B-F	77	110	N	N					2.79					131	8	1	150	1,650	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 5)

	Engine Data													Lubrication					Fuel				
Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
177	1	2	M	P	TP	900	605	6	16 x20	257	774	1933*w*	3,384	1,300	.....	200	2,342	CC	131,336	27°—30° API	No	1,635,670	1,258
260	1	2	A	P	TP	900	605	6	14¾x21	257	750	1928	617	232	181	.....	2,393	CC	19,399	27.8° API; 0.51% S; Ash—Trace; 0.6% BS&W; Tank Wagon Delivery	Yes	180,000	776
560	1	2	M	C	CH	200	134	4	12½x13¼	327	169	1924	5,419	852	.....	0	2,592	CC	....	32°—36° API; 0.07% S Delivered Partly by Tank Truck	No	....	.....
	2	2	M	C	CH	200	134	4	12½x13¼	327	169	1924	5,621		.....	0			....		No	....	.....
	3	4	A	..	TP	500	336	5	17 x24	200	408	1929	1,003	48	.....	0	10,448		....		No	....	.....
	Plant					900	604				746			900	.....	0	3,011		93,537			709,290	788
848	1	2	M	C	CH	450	302	6	15½x16	277	375	1931	5,021	....	.....	.....	....	S	....	30°—36° B; S<1.0% Ash <0.05%; BS&W<0.3%	No	....	.....
	2	2	M	C	CH	450	302	6	15½x16	277	375	1931	4,776	....	.....	.....	....		....		No	....	.....
	Plant					900	604				750			4,431	.....	.....	995		207,919			1,880,400	425
1065	1	2	M	P	TP	900	605	6	16 x20	257	774	1931	420	253	.....	50	1,493	CC	16,350	28°—30° API; 0°F Pour Test	No	221,120	874
189	1	4	M	..	TP	550	369	5	17 x24	240	470	1929	8,086	808	303	0	5,500	S& C	....	28°—30° B	No	960,540	1,187
	2	4	M	..	TP	200*x*	134	2	17 x24	200	170	1922	674	75	75	0	1,798		....		No	50,280	670
	3	4	M	..	TP	100*x*	67	1	17 x24	200	90	1915	0	0	0	0	....		....		No	0	.....
	Plant					850	570				730			883	378	0	5,190		120,968			1,010,820	1,144
153	1	2	M	P	TP	840	564	6	16 x20	257	700	1929	.....	150	.....	.....	....	....	7,070	....	....	81,080	541
494	1	2	M	P	TP	840	564	6	16 x20	257	700	1930	852	337	337	50	2,123	CC	32,440	28°—30° API	No	376,760	1,117
619	1	2	M	P	TP	840	564	6	16 x20	257	700	1929	868	513	.....	70	1,421	CC	30,500	28°—30° API	No	402,770	785
855	1	2	M	P	TP	840	564	6	16 x20	257	700	1929	4,502	667	.....	.....	5,670	Cent.	150,531	30°—36° B; S < 1.0%; Ash <0.05%; BS&W<0.3%	No	1,266,600	1,899
1056	1	2	M	P	TP	840	564	6	16 x20	257	700	1929	1,212	515	.....	0	1,980	BC	39,467	35.1° API; 41 SSU @ 100F; 0.3% S; 0.01% CC; Ash—Nil; BS&W—Trace	No	425,890	826
731	1	4	A	..	TP	825	554	4	23 x32	164	750	1926	1,269	1,636	.....	.....	640	BC, S &F	44,190	32° API; 0.5% S	No	478,260	292
853	1	2	M	C	TP	150 *m*	101	3	14 x17	257	125	1925	14	....	.....	.....	....	S &F	....	30°—36° B; S < 1.0%; Ash < 0.05%; BS&W< 0.3%	No	....	.....
	2	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1925	255	....	.....	.....	....		....		No	....	.....
	3	2	M	C	TP	360	242	6	14 x17	257	300	1926	316	....	.....	.....	....		....		No	....	.....
	Plant					810	545				675			226	.....	.....	851		11,687			100,000	443
648	1	4	M	..	TP	400	269	4	17 x24	225	333	1928	2,900	451	.....	.....	2,575	S &C	45,600	26°—30° API	No	505,600	1,12
	2	4	M	..	TP	400	269	4	17 x24	225	333	1928	3,308	562	.....	.....	2,354		56,750		No	619,770	1,10
	Plant					800	538				666			1,013	.....	.....	2,450		102,350			1,125,370	1,11
112	1	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1925	2,021	260	.....	.....	1,553	BC &S	20,739	32°—36° API	No	176.700	67
	2	2	M	C	TP	240	161	4	14 x17	257	200	1927	7,328	907	.....	.....	1,939		62,377		No	726,400	80
	3	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1925	2,178	525	.....	.....	1,244		32,716		No	290,200	55
	Plant					740	497				620			1,692	.....	.....	1,665		115,832			1,193,300	70
1128	1	4	M	..	TP	125	84	6	8 x10½	400	....	1932	3,670	....	.....	0	....	BC	16,077	36° API; 36-49 SSU @ 60F 0.19—0.21% S; BS&W—Trace	No	149,430	....
	2	4	M	..	TP	300	202	4	13½x17½	327	....	1932	2,425	....	78	0	....		21,417		No	213,590	....
	3	4	M	..	TP	300	202	4	13½x17½	327	....	1932	2,681	....	78	0	....		25,677		No	256,630	....
	Plant					725	488				....			325	.....	0	6,120		63,171			619,650	1,90
67	1	2	M	C	TP	360	242	6	14 x17	257	250	1925	2,487	1,034	.....	100	867	C &F	51,892	23° B; 52 SSU @ 100F; 0.005% S; 0.037% CC	No	512,820	49
	2	2	M	C	TP	360	242	6	14 x17	257	250	1925	1,624	610	.....	50	960		32,291		No	320,080	52
	Plant					720	484				500			1,644	.....	150	901		84,183			832,900	50
170	1	2	M	C	TP	360	242	6	14 x17	257	300	1929	2,954	684	.....	98	1,554	S,C &F	....	30.1° API; 34 SSU @ 100F; 0.8% S; 0.015% CC; Ash and BS&W—Nil (also Some 24.6° API) Delivered by Tank Truck	No	....	....
	2	2	M	C	TP	360	242	6	14 x17	257	300	1929	3,089	675	.....	94	1,647		....		No	....	....
	Plant					720	484				600			1,359	.....	192	1,600		76,309			814,242	59
394	1	2	M	C	TP	120	81	2	14 x17	257	90	......	2,603	148	.....	.....	2,110	F	10,004	....	No	79,040	53
	2	2	M	C	TP	240	161	4	14 x17	257	200	......	5,525	832	.....	.....	1,595		48,519	....	No	426,850	51
	3	2	M	C	TP	360	242	6	14 x17	257	300	......	632	194	.....	.....	1,170		5,460	....	No	57,010	29
	Plant					720	484				590			1,174	.....	.....	1,590		63,983			562,900	48
527	1	2	M	C	TP	360	242	6	14 x17	257	300	1930	2,244	....	.....	0	....	S,C &F	....	½—32°—36° API; 38 SSU @ 100F; ½—24°—26° API; 50 SSU @ 100F; All—S<0.33%;CC<0.33%; Ash—Trace; BS&W<0.25%	No	254,000	....
	2	2	M	C	TP	360	242	6	14 x17	257	300	1930	6,679	....	.....	0	....		....		No	660,300	....
	Plant					720	484				600			1,232	.....	0	2,607		99,360			914,300	74
718	1	2	M	C	TP	360	242	6	14 x17	257	300	1926	3,930	850	.....	.....	1,664	S,C &F	....	32°—36° API; 36 SSU @ 100F; 0.7% S; 0.01% CC; 0.001% Ash; BS&W—Trace	No	313,990	36
	2	2	M	C	TP	360	242	6	14 x17	257	300	1926	5,061	900	.....	.....	2,024		....		No	415,980	46
	Plant					720	484				600			1,750	.....	.....	1,850		96,838			729,970	41
19	1	2	M	C	TP	100 *m*	67	2	14 x17	257	....	......	.....	....	.....	.....	....	....	....	....	....	....	....
	2	2	M	C	CH*a*	240	161	4	12½x13½	325	....	1927	.....	....	.....	.....	....	....	....	....	....	....	....
	3	2	M	C	CH*a*	360	242	4	15½x16	275	....	1927	.....	....	.....	.....	....	....	....	....	....	....	....
	Plant					700	470				....			1,452	.....	.....	....		79,850			629,550	43
274	1	2	M	C	TP	350	235	5	14 x17	300	291	1932	6,984	....	.....	.....	....	F	....	32°—36° B; 0.25% S; 0.5% BS&W	Yes	....	...
	2	2	M	C	TP	350	235	5	14 x17	300	291	1932	6,984	....	.....	.....	....		....		Yes	....	...
	Plant					700	470				582			3,085	.....	.....	1,584		221,733			2,305,000	7
368	1	4	A	..	TP	400	269	4	16½x23	225	340	1925	5,918	974	.....	.....	2,430	CC,S &F	107,725	26.2° API; 54 SSU @ 100F; 0.648% S; 0.026% CC; Ash—Nil; BS&W—Trace	No	1,366,000	1,4
	2	4	A	..	TP	300	202	3	16½x23	225	250	1929	5,586	696	.....	.....	2,405		75,526		No	926,000	1,3
	Plant					700	471				590			1,670	.....	.....	2,420		183,251			2,292,000	1,3
851	1	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1926	219	....	.....	.....	....	S &F	....	30°—36° B; S < 1.0%; Asn <0.05%; BS&W<0.3%	No	....	...
	2	2	M	C	TP	360	242	6	14 x17	257	300	1926	424	....	.....	.....	....		....		No	....	...
	Plant					660	444				550			193	.....	.....	1,130		10,987			91,800	4

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 5, Continued)

Loading: Running Engine Capacity Factor (See Text)	Loading: Running Plant Capacity Factor (See Text)	Loading: Peak Load During Reported Period—Gross K.W.	Loading: B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	Loading: B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Maintenance and Repairs: Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	Attendance: No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
.9	79.9	600	57.5	57.0	O	Yes	B-F	90	110	N	F	246	100	0	0	0.63	Spray V. Pl. & Casings	3	6	44	.....	.....	.....	.....	1,100	177
8.3	48.3	575	64.4	61.2	O	No	A	46l	120	N	N	.....	.....	.....	.....	.....	Rings, Fuel Valves, etc.	0	0	.....	.....	.....	.....	.....	4,850	260
...		120	37.2	33.3	A	No						413	61	0	0	1.19	Piston Rings	2	6	47	.....	8	1n			560
...		120	37.2	33 3	A	No								0	0		Piston Rings	5	15	49	.....	8	2n			
...		320	72.6	69.2	A	No						0	0	0	0	0	None	0	0	2	.....	8	1n			
	39.0	320					A	75	120	N	N										.....	8	1n	.....	35	
....		260	36.7	31.6	O	No						2,689				2.99	.....	.....	.....	.....	.....	.....	.....			848
....		260	36.7	31.6	O	No											.....	.....	.....	.....	.....	.....	.....			
	63 5	520					A	60	70	N	N										.....	8c	1	.....	3,900	
7.0	87.0	550	57.5	52.3	O	Yes	B-F	90	110	N	N	300	173	0	0	0.53	Spray V. Pl. and Sle.	0	0	240	.....	.....	1n	.....	1,100	1065
2.2		300	66.7	54.2	A	Yes						.....	.....	.....	.....	.....	No Major Parts	0	0	70						189
5.7		125	72.6	67.7	A	No						.....	.....	.....	.....	.....		0	0	0	365	10	1			
0		0	72.6	....	A	No						.....	.....	.....	.....	.....		0	0	0	365	10	1			
	32.8	300					D	95	120	N	N										365	4	1	109	1,850	
....	....	540	53.6	51.3	O	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	...	14	.....	153
8.4	78.4	550	53.6	52.3	O	Yes	B-F	90	110	N	N	241	50	0	0	0.35	No Major Parts	0	0	25	.....	8	1n	.....	1,100	494
2.3	82.3	560	53.6	53.2	O	Yes	B-F	90	110	N	N	100	102	0	0	0.24	Master Fuel Pump	0	0	10	.....	8a	1n	.....	1,100	619
9.8	49.8	470	53.6	44.7	O	Yes	.....	75	90	N	N	1,666				1.98	.....	.....	.....	.....	.....	8c	1q	.....	.....	855
																	1-Set of Main Bearings;				348	8	2n			
2.3	62.3	600	53.6	56.9	O	Yes	D	105	.....	N	N	.....	.....	.....	.....	.....	1-Cam Shaft (at Mfgr's	2	681	154	348	8	1n	.....	1,200	1056
																	Expense)				51	8	1n			
8.0	68.0	600	74.9	81.1	W	Yes	D	.....	.....	N	N	241	0	0	0	0.29	(See gg 14)	1	1	1	313	8a	1	31	865	731
																					313	8a	2			
....		.....	29 4	....	A	No						149				0.18	.....	.....	.....	.....						853
....		.....	29 4	....	A	No											.....	.....	.....	.....						
....		.....	35.3	....	A	No											.....	.....	.....	.....						
	77.4	550					B	70	90	N	N										365	8	1	30	2,070	
4.9		200	64.6	48.0	A	Yes						50	25	0	0	0.19	No Major Parts	1	1,440	0						648
9.6		200	64.6	48.0	A	Yes						50	50	0	0	0.25		....	.....	.....	.....	.....	1n			
	67.6	400					B-F	90	110	N	B					0.22					.....	.....	1n	.....	1,100	
5.3		130	29.4	28.5	A	No						342	0	0	0	0.46	1-Main Bearing; Piston	0	0	20	350	10	1			112
1.6		145	35.3	31.8	A	No							0	0	0		Rings; Gaskets	1	6	24	365	4	1			
6.0		190	29.4	27.7	A	No							0	0	0			0	0	30	350	10	1			
	63 1	400					D-F	110	125	N	N										29	10	1	126	845	
3.5		90	78.1	83.7	A	Yes						0	0	0	0	0	None	0	0	.....						1128
.6		220	75.2	81.9	A	Yes						0	0	0	0	0	None	0	0	.....	365	4	1			
7.4		210	75.2	78.1	A	Yes						0	0	0	0	0	None	0	0	.....	365	10	1			
	46.4	260					D	57/80	105	N	B					0					365	10	1	61	1,000	
5.2		210	35.3	30.6	A	No						544	92	0	0	0.88	1-Piston; 8-Bearings	....	....	.....	313	8	1n			67
1.5		210	35.3	30.6	A	No								0	0		Rebabbitted	....	....	.....	313	8	1n			
	83 8	210					A	58	120	N	N										313	8	1n	.....	860	
....		.....	35.3	....	A	No						.....	.....	.....	.....	.....	1-Seized Piston	3	19	.....	.....	10	2n			170
....		.....	35.3	....	A	No						.....	.....	.....	.....	.....	1-Seized Piston	4	18½		.....	.....	1n			
	55.8	470					B-F	.....	85/100	N	N					.....								.....	50	
7.5		65	35.3	28.3	A	No						15	0	0	0	0.13		0	0	8						394
3.0		140	35.3	30.7	A	No						190	0	0	0	0.79	2-Conn. Rod B; 1M.B.	0	0	36	365	10	1½			
7.3		170	35.3	24.8	A	No						0	0	0	0	0		0	0	0	365	10	1			
	45.0	170					A	75	110	N	N					0.28					365	4	1	53	2,650	
																	12-D.S. Rings; 24 Inj. Nozzle Tips	1	1/20	90	.....	.....	.....			527
3.8		260	35.3	37.9	A	Yes						293	0	0	0		1-Lubricator	1	1/12	30	351	8b	1			
.8		260	35.3	37.9	A	Yes							0	0	0						42	8	1	99	750	
	42.4	330					D-F	110	116	N	N					0.41										
.0		200	35.3	29.2	A	No						760				1.06	(See gg 15)	2	.....	.....						718
.0		200	35.3	29.2	A	No												3	.....	.....	313	8b	1			
	33.5	200					B	.....	.....	N	N										156	8	1	75	1,200	
...		.....	29 4	....	A	....						.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....			19
...		.....	45.0	....	A	....						.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....			
...		.....	44 3	....	A	....						.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....			
	....	185					.....	.....	.....	.....	.....					.....								55	.....	
...		215	35.3	32.3	A	Yes						.....	.....	.....	.....	.....	Conn. Rod Bearings;	1	12	0	.....	8	1			274
...		215	35.3	32.3	A	Yes						.....	.....	.....	.....	.....	Gaskets	2	18	0	.....	8	1			
	70.2	425					B-F	95	102	F	N					.....					.....	8	1	.....	700	
.8		272	73.8	74.6	A	No						384	0	0	0	0.96	1-Intercooler Tube	2	16	48	231	11a	1			368
.0		200	73.8	73.0	A	No						204	0	0	0	0.68	Blowout; 1-Piston	0	0	45	192	12	1			
	84.4	472					B	60	110	N	N					0.84					63	8b	1	342	1,400	
...		.....	29 4	....	A	No						698				1.06	.....	...	.....	.....						851
...		.....	35.3	....	A	No											.....	...	.....	.....						
	62.6	490					B	70	90	N	N										365	8	1	24	2,500	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 6)

	Engine Data													Lubrication					Fuel				
Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
810	1	2	M	C	TP	150 *m*	101	3	14 x17	257	125	1920	19	10	.....	.....	285	None	231	28°—30° API; S < 0.5%	No	570	57
	2	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1919	110	25	.....	.....	880		1,856		No	6,600	264
	3	2	M	C	TP	300 *m*	202	6	14 x17	257	250	1922	238	64	.....	.....	1,116		4,607		No	24,730	386
	Plant					650	437				545			99	.....	.....	972		6,694			31,900	322
1146	1	2	M	C	TP	140	94	2	14 x17	300	111	1931	4,212	....	.....	.....	....	BC, S &F	17,500	28°—36° API 0.5% S	No	162,900	.....
	2	2	M	C	TP	210	141	3	14 x17	300	170	1931	1,116	....	.....	.....	....		10,145		No	100,400	.....
	3	2	M	C	TP	280	188	4	14 x17	300	230	1931	3,432	....	.....	.....	....		22,860		No	231,700	.....
	Plant					630	423				511			902	.....	5	1,980		50,505			495,000	549
529	1	2	M	C	TP	100 *m*	67	2	14 x17	257	75	1922	1,230	108	.....	0	1,139	BC	4,893	32°—36° API	No	....	.....
	2	2	M	C	TP	100 *m*	67	2	14 x17	257	75	1922	1,326	102	.....	0	1,300	BC	4,965		No	....	.....
	3	2	M	C	TP	120	81	2	14 x17	257	90	1927	4,272	309	.....	0	1,659	BC&F	17,985		No	....	.....
	4	2	M	P	TP	300	201	6	10½x12½	360	250	1931	4,482	517	.....	0	2,600	BC	42,075		No	....	.....
	Plant					620	416				490			1,036	.....	0	2,038		69,918			558,084	539
359	1	2	M	C	TP	240	161	4	14 x17	257	200	1929	3,119	439	439	.....	1,704	F	20,666	....	No	138,800	316
	2	4	M	..	TP	375	252	6	12 x15½	360	310	1932	5,641	654	654	.....	3,234		45,263	....	No	371,200	567
	Plant					615	413				510			1,093	1,093	.....	2,619		65,929			510,000	467
431	1	2	M	C	TP	100 *m*	67	2	14 x17	257	75	1922	.....	....	.....	.....	....	F	....	34° API	No	....	.....
	2	2	M	C	TP	150 *m*	101	3	14 x17	257	125	1923	.....	....	.....	.....	....		....		No	....	.....
	3	2	M	C	TP	360	242	6	14 x17	257	300	1930	.....	....	.....	.....	....		....		No	....	.....
	Plant					610	410				500			1,160	.....	.....	....		50,735			451,900	389
32	1	4	M	..	TP	600*y*	403	5	17¾x22	234*z*	572	1928	2,472	1,333	.....	200	1,113	S&F	63,867	36° API; CC and Ash—Trace; BS&W—Nil	No	726,050	544
61	1	4	M	..	TP	300	202	3	17¾x22	225	275	1928	5,533	....	.....	.....	....	CC &F	....	30° API; 40 SSU @ 100 F; 0.3% S; 0.15% CC; 0.25% BS&W; Ash—Trace	No	651,300	.....
	2	4	M	..	TP	300	202	3	17¾x22	225	275	1928	5,599	....	.....	.....	....		....		No	608,300	.....
	Plant					600	404				550			1,022	.....	75	3,268		110,379			1,259,600	1,231
106	1	4	A	..	TP	600	403	6	17 x25	200	....	1929	5,432	706	.....	.....	4,616	....	141,092	....	....	1,570,920	2,225
228	1	4	A	..	TP	300	202	3	17 x25	200	250	1925	5,198	....	.....	.....	....	S &F	....	24°—26° API; 150 SSU @ 100F; 1.0%CC; 1.0% BS&W; S—Trace	No	....	.....
	2	4	A	..	TP	300	202	3	17 x25	200	250	1925	5,198	....	.....	.....	....		....		No	....	.....
	Plant					600	404				500			1,750	360	.....	1,782		187,000			1,898,000	1,084
644	1	2	M	C	TP	240	161	4	14 x17	257	196	1931	7,217	945	945	0	1,832	BC	69,970	32°—36° B; 0.5% S; 0.5% BS&W	No	....	.....
	2	2	M	C	TP	360	242	6	14 x17	257	300	1931	1,543	413	413	0	1,344		26,200		No	....	.....
	Plant					600	403				496			1,358	1,358	0	1,683		96,170			913,700	672
809	1	4	A	..	TP	600	403	6	16½x24	200	500	1923	353	70	.....	.....	3,026	S&F	10,016	28°—30° API; S <0.5%	No	76,300	1,090
1094	1	4	A	..	TP	600	403	6	16¼x23	225	513	1928	1,658	391	.....	70	2,542	S&C	47,857	....	No	596,800	1,526
1096	1	4	A	..	TP	600	403	6	16¼x23	225	513	1928	2,606	475	.....	70	3,290	S&C	58,000	....	No	733,520	1,544
410	1	2	M	C	TP	150 *m*	101	3	14 x17	257	125	1923	3,918	....	.....	.....	....	C	....	....	No	198,200	.....
	2	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1923	7,850	....	.....	.....	....		....	....	No	608,830	.....
	3	2	M	C	TP	240	161	4	14 x17	257	200	1928	1,421	....	.....	.....	....		....	....	No	115,440	.....
	Plant					590	396				495			1,829	.....	.....	1,366		110,292			922,470	504
862	1	2	M	C	TP	75 *m*	50	2	12 x15	300	60	1920	445	....	.....	.....	....	CC &F	....	33.1° API; 0.6% S; Trace—BS&W	No	....	.....
	2	2	M	C	TP	75 *m*	50	2	12 x15	300	60	1922	985	....	.....	.....	....		....		No	....	.....
	3	2	M	C	TP	180	121	3	14 x17	257	150	1925	4,345	648	.....	70	1,207		....		No	....	.....
	4	4	A	..	TP	258	173	3	16½x24½	180	225	1918*aa*	4,950	752	433	169	1,698		....		No	....	.....
	Plant					588	394				495			....	.....	.....	....		76,756			653,190	.....
808	1	2	M	P	TP	560	376	4	16 x20	257	470	1930	386	115	.....	0	1,880	BC	8,434	28°—30° API; S <0.5%; Delivered Partly in Tank Trucks	No	106,700	928
852	1	2	M	P	TP	560	376	4	16 x20	257	460	1928	690	106	.....	.....	3,644	BC	15,720	30°—36° B; S <1.0%; Ash <0.05%; BS&W<0.3%	No	174,660	1,647
246	1	2	M	C	TP	100 *m*	67	2	14 x17	257	60	1918	2,350	....	.....	0	....	C, S, &F	....	36°—40° API; Delivered Partly by Tank Truck	No	....	.....
	2	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1922	4,435	....	.....	0	....		....		No	....	.....
	3	2	M	C	TP	240	161	4	14 x17	257	200	1929	2,875	....	.....	0	....		....		No	....	.....
	Plant					540	362				430			1,239	.....	0	1,461		56,880			412,525	333
540	1	2	M	C	TP	360	242	6	14 x17	257	....	1930	5,361	....	.....	30	....	F	....	32°—36° API 0.5% S	No	....	.....
	2	2	M	C	TP	180	121	3	14 x17	257	....	1926	3,399	....	.....	20	....		....		No	....	.....
	Plant					540	363				....			2,965	.....	50	858		87,120			700,500	236
541	1	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1922	2,834	582	.....	.....	974	BC &S	26,132	36° API	No	206,500	355
	2	2	M	C	TP	200 *m*	134	4	14 x17	257	170	1922	2,712	542	.....	.....	1,001		25,076		No	192,700	356
	3	2	M	C	TP	140	94	2	14 x17	300	111	1931	5,354	423	.....	.....	1,772		24,145		No	251,700	595
	Plant					540	362				451			547	.....	.....	1,202		75,353			650,900	421
211	1	4	A	..	TP	510	342	6	14 x21	277	438	1932	.....	1,741	.....	.....	....	....	93,221	....	....	1,151,190	662
772	1	4	A		TP	250	168	4	13¾x17½	257	250	1916	440	138	.....	15	797	CC	5,530	28°—30° API 0°F Pour Test	No	54,770	397
	2	4	A	..	TP	250	168	4	13¾x17½	257	263	1916	428	135	.....	15	793		5,330		No	52,802	391
	Plant					500	336				513			273	.....	30	795		10,860			107,572	394
424	1	2	M	C	TP	240	161	4	14 x17	257	200	1929	4,175	799	.....	35	1,254	F	33,071	Delivered Partly by Tank Truck	No	309,325	387
	2	2	M	C	TP	240	161	4	14 x17	257	200	1929	4,606	844	.....	35	1,310		37,996		No	356,275	422
	Plant					480	322				400			1,643	.....	70	1,282		71,067				405
501	1	2	M	C	TP	120	81	2	14 x17	257	90	1925	2,521	289	.....	40	1,046	CC, S &F	11,170	....	No	63,845	221
	2	2	M	C	TP	120	81	2	14 x17	257	90	1925	3,533	513	.....	40	826		15,259	....	No	90,604	177
	3	2	M	C	TP	240	161	4	14 x17	257	200	1929	4,054	612	.....	30	1,590		29,152	....	No	262,600	429
	Plant					480	323				380			1,414	.....	110	1,201		55,581			417,049	295
124	1	2	M	C	TP	80	54	2	12 x15	300	65	1927	1,181	177	.....	0	534	BC, S &F	4,675	30° API; 1.91% S	No	....	.....
	2	2	M	C	TP	180	121	3	14 x17	257	150	1930	4,489	743	.....	0	1,087		28,408		No	....	.....
	3	2	M	C	TP	210	141	3	14 x17	300	170	1931	4,329	664	.....	0	1,368		24,790		No	....	.....
	Plant					470	316				385			1,584	.....	0	1,143		57,873			515,200	325

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 6, Continued)

Loading: Factor (See Text)	Loading: Running Plant Capacity Factor (See Text)	Loading: Peak Load During Reported Period—Gross K.W.	Loading: B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	Loading: B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used?	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Maintenance and Repairs: Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	Attendance: No. of Shifts in Period	Attendance: No. of Hours per Shift (See Note ff)	Attendance: No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
7		50	29.4	14.6	A	No						0	0	0	0	0	None	0	0	0						810
8		80	29.4	17.6	A	No						0	0	0	0	0	None	0	0	0						
4		125	29.4	18.2	A	No						0	0	0	0	0	None	0	0	0						
	49.3	225					B-F	90	115	N	N										.....	....	1	.....	1,500	
1		70	35.3	26.2	A	Yes						28	0	0	0	0.20	Bearing Rebabb.; Gask.	0	0	32	348	10	1			1146
8		140	35.3	35.1	A	Yes						32	0	0	0	0.15	Bearing Rebabb.; Gask.	0	0	24	348	10	1			
9		200	35.3	37.7	A	Yes						35	0	0	0	0.12	Bearing Rebabb.; Gask.	0	0	64	348	10	1			
	41.3	200					B	100	112	N	B					0.15					52	10	1	39	800	
..		55	29.4	24.1	A	No						0	0	0	0	0	None	0	0	0						529
..		55	29.4	24.1	A	No						0	0	0	0	0	None	0	0	0	365	6	1½			
..		65	35.3	28.3	A	No						6	5	0	0	0.10	None	0	0	40	365	6	1			
..		180	50.8	45.5	O	Yes						24	20	240	22	1.02	1-Cyl. and Piston	1	504ee	96	365	6	1			
	39.4	180					D	95	115	B	B					0.51					365	6	1	53	700	
6		160	35.3	35.1	A	Yes						77	74	0	0		....	0	0	8	365	10	1			359
1		170	78.4	52.9	A	Yes								0	0	0.25	1-New Oil Line—Improved Design	5	45	214	365	10	1			
	26.5	170					D-F	......	115	N	N										365	8	1	48	1,600	
..		......	29.4	....	A	No						16	0	0	0	0.16	Spray Valve Tips; Gask.	0	0	16	358	8	1			431
..		......	29.4	....	A	No						220	0	0	0	1.47	(See gg 16)	2	150	30	358	8	1			
..		......	35.3	....	A	No						58	0	0	0	0.16	1-Inj. Rock. Arm; Gask.	0	0	72	358	8	1			
	....	175					B-F	80	110	N	N					0.48					21	8	1	51	212	
8	72.8	450	74.6	83.4	A	No	A	95	110	N	B	28	6	0	0	0.06	No Major Parts	0	0	72	365	12a	1	81	9,200	32
3		220	64.7	70.5	A	No						38	180	0	0	0.73	No Major Parts	0	0	336	365	8	½			61
8		220	64.7	70.5	A	No						11	172	120	73	1.25	2-Sets Crank Bearings	2	75	408	365	8	½			
	56.2	440					B	85	115	T	N					0.99					365	8	½	.....	620	
8	71.8	460	69.8	79.7	A	....	......	......	......	....	....	......	......	......	......	......	....	....	....	......	....	....	....	151	.....	106
..		200	69.8	69.1	A	No						150	40	0	0	0.63	Governor Parts	2	20	40	365	8	4n			228
..		210	69.8	72.6	A	No						50	0	0	0	0.17	....	0	0	40	365	8	2n			
	90.7	375					A	63	100	N	N					0.40					365	8	2n	.....	272	
..		152	35.3	33.3	A	No						148	0	0	0	0.25	Water Piping; Nozzles and Tips; Gaskets	0	0	......	313	10	1¼n			644
..		250	35.3	36.5	A	No							0	0	0			0	0	......	313	10a	1n			
	59.5	265					C	90	130	N	N										156	12	1n	.....	579	
6	53.6	400	77.1	76.5	A	No	B-F	80	108	N	N	0	0	0	0	0	None	0	0	0	.....	....	1	.....	1,900	809
4	89.4	410	73.8	75.1	A	No	B-F	90	110	N	B	301	111	0	0	0.69	Main Shaft T. B.	0	0	240	.....	....	....	.....	1,100	1094
3	69.8	410	73.8	75.1	A	Yes	B-F	90	110	N	N	560	202	0	0	1.27	....	0	0	236	....	8b	1n	.....	1,100	1096
1		75	29.4	21.8	A	No						......	......	......	......	......	....	0	0	......						410
		100	29.4	21.8	A	No						......	......	......	......	......	2-Main Bearings	0	0	......	365	8	1			
1		115	35.3	25.1	A	No						......	......	......	......	......	....	0	0	......	365	8	1			
	55.0	260					D	100	105	N	N					......					365	8	1	99	1,850	
..		35	29.1	20.4	A	No											None	0	0	24						862
..		35	29.1	20.4	A	No						2,489				4.23	None	0	0	24	348	8	1			
..		95	35.3	27.7	A	No											1-Conn. Rod Bearing	2	524		348	8	1			
..		180	72.2	75.1	A	No											New Rings & Bearings	2	1,128		348	8	1			
	44.9	224					B	90	110	N	N										51	8	1	70	221	
5	73.5	425	53.6	60.6	O	Yes	B-F	65	75	F	N	0	0	0	0	0	None	0	0	0	.....	....	1	.....	1,900	808
	67.3	320	53.6	45.6	O	No	A	60	80	N	N	114				0.20	....	....	....	......	.....	....	1n	.....	3,556	852
.		58	29.4	25.4	A	No						23	15	0	0	0.07	Gaskets and Misc. Small Parts	0	0	15						246
.		95	29.4	20.8	A	No								0	0			0	0	28	365	10	1			
.		120	35.3	26.3	A	No								0	0			0	0	28	365	10	1			
	33.9	160					B	60/80	110	B	N										365	4	1	45	5,000	
.		260	35.3	37.9	A	Yes						13	27	0	0	0.07	Pist. Rings, Gask., etc.	0	0	14	365	8	1			540
.		110	35.3	32.1	A	Yes								0	0		Pist. Rings, Gask., etc.	0	0	10	365	8	1			
	41.0	280					D-F	......	100	N	N										365	8	1	76	525	
		120	29.4	26.3	A	No						215	0	0	0	0.40	No Major Parts	0	0	200						541
		120	29.4	26.3	A	No							0	0	0		1-Piston	0	0	200	365	5	1			
		90	35.3	33.8	A	No							0	0	0		1-Conn. Rod Bearing	0	0	72	365	9½	1			
	52.2	200					B	110	130	N	N										365	9½	1	73	780	
.	....	330	75.2	72.6	A	No	......	......	......	....	....	......	......	......	......	......	....	....	....	......	.....	....	....	132	.....	211
		160	74.1	70.6	A	Yes						201	137	0	0	0.68	No Major Parts	0	0	168						772
		160	74.1	70.6	A	Yes								0	0			0	0	144	.....	8	1n			
	73.8	320					B-F	90	110	N	N										.....	8	1n	.....	1,100	
		160	35.3	35.1	A	No						0	0	0	0	0	None	1	4	192	350	11a	1			424
																					365	2	1			
	47.0	160	35.3	35.1	A	No	B	75	100	N	N	0	0	0	0	0	None	0	0	192	30	11	1	71	225	
		220																								
		40	35.3	17.4	A	No						545	28	0	0	1.19	Piston Rings	0	0	32						501
		65	35.3	28.3	A	No								0	0		P. & R.; Reboring	0	0	96	365	5/10	1			
		135	35.3	29.6	A	No								0	0		1-Cyl. and Piston	1	1/6	10	365	10	1			
	36.5	135					B-F	90	110	N	N										365	9	1	.....	1,106	
.		45	31.1	25.9	A	Yes						40	0	0	0	0.50	4-Special Rings	....	....	......						124
.		100	35.3	29.2	A	Yes						32	0	0	0	0.18	12-Std. Rings	....	....	......	365	8	1			
..		120	35.3	30.0	A	Yes						9	0	0	0	0.04	6-Std. Rings	....	....	......	365	8	1			
	42.4	150					B	70	90	N	N					0.17					365	8	1	55	4,550	

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 7)

	Engine Data													Lubrication					Fuel				
Plant Number	Engine Designation	Engine Cycle	Injection System (Notes)	Scavenging System (Notes)	Trunk Piston or Crosshead?	Rated B.H.P.	Equivalent K.W.—90% Generating Efficiency	Number of Cylinders	Cylinder Dimensions Bore x Stroke—Inches	Rated R.P.M.	Generator Rating—K.V.A.	Year Engine Started to Work	Engine Hours Operated in Reported Period	Total Gallons of New Lubricating Oil Used	Gals. of New Lub. Oil for Cylinder Lub. Only	Gals. of Unfit Lubricating Oil Discarded	Rated H.P. Hours per Gal. of New Lubricating Oil	Lubricating Oil Treatment (See Notes)	Fuel Oil Used—Gallons	Nature of Fuel Oil Used (See Notes)	Is Fuel Centrifuged?	Gross Output—K.W. Hrs.	Gross K.W. Hrs. per Gallon of New Lubricating Oil
315	1	2	M	C	TP	240	161	4	14 x17	257	200	1929	3,320	413	.....	.....	1,928	F	30,750	32°—36° API	No	240,200	582
	2	2	M	C	TP	120	81	2	14 x17	257	90	1926	4,466	486	.....	.....	1,102	F	23,600		No	156,900	323
	3	2	M	C	TP	100 m	67	2	14 x17	257	90	1917	793	166	.....	.....	478	None	4,680		No	21,800	131
	Pl	an	t			460	309				380			1,065	.....	.....	1,325		59,030			418,900	393
471	1	2	M	C	TP	150 m	101	2	14½x16	327	94	1924	2,330	.....	.....	.....	.....	BC	.....	35° API	No	.....	.....
	2	2	M	C	TP	300 m	202	4	14½x16	327	219	1927	2,331	.....	.....	.....	.....		.....		No	.....	.....
	Pl	an	t			450	303				313			385	.....	.....	2,725		50,406			428,110	1,112
695	1	2	M	C	TP	165	111	3	12 x15	360	150	1931	2,536	.....	.....	0	.....	BC &F	.....	28°—32° API	No	.....	.....
	2	2	M	C	TP	165	111	3	12 x15	360	150	1931	2,609	.....	.....	0	.....		.....		No	.....	.....
	3	2	M	C	TP	120	81	2	14 x17	257	90	1931	4,536	.....	.....	0	.....		.....		No	.....	.....
	Pl	an	t			450	303				390			1,513	.....	0	921		48,230			456,140	302
885	1	2	M	C	TP	180	121	3	14 x17	257	150	1930	6,672	.....	.....	.....	.....	BC, S &F	.....	.....	No	.....	.....
	2	2	M	C	TP	180	121	3	14 x17	257	150	1926	6,670	.....	.....	.....	.....		.....	.....	No	.....	.....
	3	2	M	C	TP	75 m	50	2	12 x15	300	60	1923	1,068	.....	.....	.....	.....		.....	.....	No	.....	.....
	Pl	an	t			435	292				360			1,626	.....	.....	1,526		99,991			778,200	479
335	1	4	A	..	TP	250	168	4	13¾x17¼	257	219	1924	6,090	442	332	110	3,444	F &S	33,477	28°—30° API	No	342,910	776
	2	4	A	..	TP	180	121	4	11¾x15	300	150	1920	2,670	229	188	41	2,098		15,788	0.5% S	No	148,410	648
	Pl	an	t			430	289				369			671	520	151	2,985		49,265			491,320	732
1209	1	4	M	..	TP	215	144	3	14½x18	300	188	1930	4,426	.....	.....	.....	.....	BC &F	34,170	38°—40° API	No	262,700	.....
	2	4	M	..	TP	215	144	3	14½x18	300	188	1930	4,344	.....	.....	.....	.....		31,844		No	252,790	.....
	Pl	an	t			430	288				376			444	14	.....	4,250		66,014			515,490	1,160
247	1	2	M	C	TP	240	161	4	14 x17	257	200	1928	4,200	.....	.....	0	.....	S, C &F	.....	34° B	No	258,090	.....
	2	2	M	C	TP	100 m	67	2	14 x17	257	75	1920	6,624	.....	.....	0	.....		.....		No	227,150	.....
	3	2	M	C	TP	50 m	34	1	14 x17	257	40	1915	200	.....	.....	0	.....		.....		No	4,800	.....
	Pl	an	t			390	262				315			632	.....	0	2,658		62,109			490,040	775
187	1	2	M	C	TP	140	94	2	14 x17	300	111	1931	5,840	.....	.....	.....	.....	CC	.....	32°—36° API	No	.....	.....
	2	2	M	C	TP	210	141	3	14 x17	300	170	1931	2,920	.....	.....	.....	.....		.....		No	.....	.....
	Pl	an	t			350	235				281			1,285	.....	.....	1,113		33,355			315,879	246
688	1	2	M	C	TP	50 m	34	1	14 x17	257	38	1923	3,156	.....	.....	.....	.....	CC, S &F	.....	36° API	No	.....	.....
	2	2	M	C	TP	120	81	2	14 x17	257	90	1926	5,925	.....	.....	.....	.....		.....		No	.....	.....
	3	2	M	C	TP	180	121	3	14 x17	257	150	1927	3,334	.....	.....	.....	.....		.....		No	.....	.....
	Pl	an	t			350	236				278			720	.....	100	2,040		59,200			412,000	572
774	1	4	A	..	TP	165	111	4	11¾x15	277	135	1917	452	60	.....	5	1,243	CC	3,200	28°—30° API	No	32,600	543
	2	4	A	..	TP	180	121	4	11¾x15	300	135	1920	406	65	.....	10	1,124		3,400	0°F Pour Test	No	34,222	526
	Pl	an	t			345	232				270			125	.....	15	1,181		6,600			66,822	535
857	1	2	M	C	TP	180	121	3	14 x17	257	150	1929	5,322	.....	.....	.....	.....	S,C &F	.....	29° B	No	287,600	.....
	2	2	M	C	TP	150 m	101	3	14 x17	257	90	1927	3,618	.....	.....	.....	.....		.....	1.0% S	No	124,536	.....
	Pl	an	t			330	222				240			1,216	.....	.....	1,234		60,936			412,136	339
265	1	2	M	C	TP	60	40	1	14 x17	257	48	1927	2,190	.....	.....	.....	.....	F	.....	36°—40° API	No	.....	.....
	2	2	M	C	TP	120	81	2	14 x17	257	90	1927	3,285	.....	.....	.....	.....		.....		No	.....	.....
	3	2	M	C	TP	140	94	2	14 x17	300	111	1931	3,285	.....	.....	.....	.....		.....		No	.....	.....
	Pl	an	t			320	215				249			613	.....	250	1,610		33,505			262,100	428
1055	1	4	M	..	TP	320	215	4	15 x18½	300	265	1932	8,535	325	3	0	8,400	BC	70,807	16°—18° API	No	521,127	1,603
27	1	2	M	C	TP	75 m	50	2	12 x15	300	.....	1926	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	2	M	C	CHa	240	161	4	12½x13½	325	.....	1926	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	Pl	an	t			315	211				.....			992	.....	.....	.....		32,820			203,800	205
737	1	2	M	C	TP	100 m	67	2	14 x17	257	75	1929cc	5,642	502	.....	0	1,124	S& F	23,532	.....	No	221,788	442
	2	2	M	C	TP	75 m	50	2	12 x15	300	60	1926cc	5,237	380	.....	0	1,034		18,598	.....	No	144,102	379
	3	2	M	C	TP	50 m	34	1	14 x17	257	40	1918	2,406	229	.....	0	525		5,347	.....	No	42,776	187
	4	2	M	C	TP	80 m	54	2	12½x13½	300	75bb	1927	101	7	.....	0	1,154		423	.....	No	1,260	180
	Pl	an	t			305	205				250			1,118	.....	0	971		47,900			409,926	367
382	1	4	M	..	TP	150	101	4	9½x14	300	140	1927	6,630	.....	.....	.....	.....	BC	.....	36°—40° API; 1.0% S; Ash—Nil; CC—Trace	No	168,500	.....
	2	4	M	..	TP	150	101	4	9½x14	300	135o	1927	2,623	.....	.....	.....	.....		.....		No	85,500	.....
	Pl	an	t			300	202				.....			333	.....	.....	4,170		25,026			254,000	703
858	1	2	M	C	TP	150 m	101	3	14 x17	257	125	1929cc	4,071	.....	.....	.....	.....	S, C&F	.....	29° B	No	112,200	.....
	2	2	M	C	TP	120	81	2	14 x17	257	90	1929	4,693	.....	.....	.....	.....		.....	1.0% S	No	99,400	.....
	Pl	an	t			270	182				215			1,161	.....	.....	1,011		39,671			211,600	182
169	1	4	M	..	TP	240	161	6	10¾x13¾	327	200	1928	1,809	177	.....	0	2,452	CC	11,207	31° API; 37 SSU @ 100F; 0.61% S; 0.06% CC; Ash—Nil; BS&W—Trace	No	84,090	475
677	1	2	M	C	TP	240	161	4	14 x17	257	200	1928	1,971	600	.....	.....	788	Cent.	18,000	32°—36° API	No	235,000	392
591	1	4	A	..	TP	225	151	3	18¼x24	150	200	1921	3,265	587	367	180	1,251	None	36,934	32°—36° API; 0.5% S	No	329,143	56
984	1	4	A	..	TP	225	151	6	9½x13½	400	219	1928	396	35	.....	35	2,545	F	3,170	Delivered by Tank Wagon	No	29,000	82
318	1	2	M	C	CHa	100	67	2	12½x13½	327	70bb	1922dd	.....	.....	.....	0	.....	S	.....	37° API	No	29,900	....
	2	2	M	C	TP	50 m	34	1	14 x17	257	35bb	1920	.....	.....	.....	0	.....		.....		No	74,000	....
	3	2	M	C	TP	37½m	25	1	12 x15	300	23bb	1924	.....	.....	.....	0	.....		.....		No	25,830	....
	4	2	M	C	TP	25 m	17	1	10 x13	325	15bb	1918	.....	.....	.....	0	.....		.....		No	14,500	....
	Pl	an	t			212½	143				143			624	.....	0	.....		25,815			144,230	23
1193	1	2	M	C	TP	200 m	134	4	14 x17	257	170	1924	4,944	606	.....	.....	1,630	S&F	50,968	26°—30° B; 0.5% S; 0.1% CC; 0.1% BS&W	No	424,400	70
733	1	2	M	C	CHa	100	67	2	12½x13½	327	75	1922	35	7	0	0	500	None	.....	Delivered by Tank Wagon		1,130	....
	2	2	M	C	TP	75 m	50	2	12 x15	300	60	1914	33	5	0	0	495	F	.....		No	1,005	....
	Pl	an	t			175	117				135			12	0	0	498		502		No	2,135	50
646	1	2	M	C	TP	120	81	2	14 x17	257	90	1927	998	63	.....	.....	1,900	BC&F	2,192	38°—40° API	No	8,990	14
1201	1	2	M	C	TP	x25 m	17	1	10 x12	325	25bb	1930cc	.....	.....	.....	.....	.....	F	.....	28°—38° API; Delivered Partly by Tank Wagon	No	18,135	....
	2	2	M	C	TP	75 m	50	1	14 x17	300	53	1932cc	.....	.....	.....	.....	.....		.....		No	40,415	....
	Pl	an	t			100	67				78			431	.....	.....	.....		11,056			58,550	13

TABLE III—ENGINE DETAILS AND OPERATING INFORMATION (Page 7, Continued)

Loading: Running Plant Capacity Factor (See Text)	Loading: Peak Load During Reported Period—Gross K.W.	Loading: B.M.E.P. at Rated B.H.P.—Lbs. per Sq. In.	Loading: B.M.E.P. at Peak Load—90% Generating Efficiency	Piston Cooling (See Notes)	Are Air Filters Used?	Type Cooling System (See Text)	Average Temperature Incoming Cooling Water—Degs. F.	Average Temperature Outgoing Cooling Water—Degs. F.	Purpose for which Jacket Water Heat is Utilized (See Notes)	Purpose for which Exhaust Heat is Utilized (See Notes)	Maintenance and Repairs: Cost of Engine Regular Upkeep—Dollars: Material	Cost of Engine Regular Upkeep—Dollars: Extra Labor	Cost of Repairs for Engine Accidents—Dollars: Material	Cost of Repairs for Engine Accidents—Dollars: Extra Labor	Total Engine Maintenance in Dollars per Rated B.H.P. per Year	Major Engine Parts Renewed During Reported Period (See Note gg)	No. of Enforced Engine Shutdowns	Total Duration of Enforced Engine Shutdowns—Hours	Total Engine Maintenance Time Not Inc. in Enforced Shutdown Time—Hours	Attendance: No. of Shifts in Period	No. of Hours per Shift (See Note ff)	No. of Attendants per Shift	Output per Man-Hour—Net K.W. Hrs.	Plant Altitude—Feet Above Sea Level	Plant Number
	165	35.3	36.2	A	No						292	0	0	0	0.63	Valves; Springs; Injection Nozzles, etc.	0	0	14						315
	84	35.3	36.6	A	No							0	0	0			0	0	10						
	67	29.4	29.4	A	No							0	0	0			0	0	0	365	12	1½			
44.2	202					A	50	100	N	N										365	12	1	.....	2,565	
	65	35.6	22.9	A	Yes						279	52	36	21		Pistons; Bearings;	2	3½	15						471
	155	35.6	27.3	A	Yes										0.86	Piston Pins and	2	2½	31						
60.8	220					A	85	130	P	N						Bushings; etc.				259	9	1	181	.....	
	105	35.6	33.7	A	Yes						125				0.76	Piston Rings & Gaskets	....	.....	.....						695
	105	35.6	33.7	A	Yes						125				0 76	Piston Rings & Gaskets	....	.....	.....	365	8	1			
	72	35.3	31.4	A	Yes						1,029				8.58		....	.....	.....	365	8	1			
48.8	165					A	60	100	....	B					2.84	(See gg 17)				365	8	1	50	300	
	95	35.3	27.7	A	No						1,738				4.00	....	10	120	600	313	8	1			885
	95	35.3	27.7	A	No											....	4	48	672	313	8	1			
	43	29.1	25.0	A	No											....	0	0	200	313	8	1			
46.7	233					D	75/95	95/120	N	N										156	8	1	84	1,464	
	152	74.1	67.1	A	No						129	0	290	0	1.68	1-Lub.Oil P; Exh.&A.V.	1	240	0	365	7	1			335
																				339	7	1			
	115	73.0	69.4	A	No						0	0	0	0	0		0	0	0	339	8	1			
																				352	2	1			
36.5	152					A	55	110	S	B					0.98					52	8	1	55	867	
	154	63.7	68.1	A	No						7	0	0	0	0.02	8-Spray Valve Check	0	0	......	365	4	1			1209
	147	63.7	65.0	A	No							0	0	0		bodies; 24-Spray Valve	0	0	......	365	10	1			
40.7	154					D	70	110	N	N						Strainers; Gaskets				365	10	1	54	1,290	
	158	35.3	34.6	A	No						88	0	0	0	0.23	Replaced Snap Rings	0	0	12						247
	75	29.4	32.9	A	No							0	0	0		with Double Seal	0	0	12	365	8	1			
	25	29.4	21.9	A	No							0	0	0		Rings	0	0	0	365	8	1			
43.4	225					A	55	120	N	N										365	8	1	56	5,000	
	110	35.3	41.3	A	No						17	0	0	0	0.12	Reconditioned Spray	0	0	43	355	10a	1			187
	140	35.3	35.0	A	No						29	0	0	0	0.14	Nozzles	0	0	21	361	4	1			
32.9	140					B-F	......	105	N	N					0.13					25	1¼	1	34	560	
	......	29.4	....	A	No						125	0	40	0	0.47	1-Piston Pin and Bushing	0	0	12						688
	......	35.3	....	A	No							0		0			1	10	30	365	8	1			
	......	35.3	....	A	No							0		0			0	0	35	365	8	1			
41.8	160					D-F	......	......	N	N										365	8	1	46	870	
	100	72.6	65.4	A	No						0	0	0	0	0	None	0	0	0						774
	100	73.1	60.4	A	No						0	0	653	200	4.74	1-Cyl. Head and Piston	1	700	0						
67.4	100					B-F	90	110	N	N					2.47					.....	8	1n	.....	1,100	
	......	35.3	....	A	No						2,261				6.85	Cylinders and Pistons;	....	.....	.....						857
	......															Crank Pin Bearings	....	.....	.....	313	8b	1			
40.8	110	29.4	....	A	No	B	......	......	L	N										156	8	1	42	4,010	
	3 0	35.3	26.3	A	No						80	0	100	0	0.56	1-Cyl. Head; Rings;	....	.....	.....						265
	65	35.3	28.5	A	No							0		0		Gaskets; etc.	....	.....	.....	365	8	1			
	100	35.3	37.6	A	No							0		0			....	.....	.....	365	8	1			
39.6	115					B-F	90	110	N	N										365	8	1	29	894	
28.4	180	64.6	54.1	A	Yes	D	125	140	N	N	0	0	0	0	0	None	....	.....	225	313	8b	1n	.....	1,053	1055
																				156	8	1n			
	......	29.1	....	A	....						......	......	......	......	......	....	....	.....	.....	....	....	....			27
	......	45.0	....	A	....						......	......	......	......	......	....	....	.....	.....	....	....	....			
....	75					......	......	......	......	......					......								23	.....	
	70	29.4	30.7	A	No						22	338	0	0	1.18	Piston Rings	....		525						737
	55	29.1	32.0	A	No								0	0			....		504						
	30	29.4	25.9	A	No								0	0			....		314	365	10	1n			
	50	33.8	31.3	A	No								0	0			....		10	365	6.8	1n			
56.3	110					B	70	110	N	N										365	6.8	1n	.....	1,300	
	......	99.7	....	A	Yes						4	0	0	0	0.01	Discharge Valve	0	0	......						382
	......	99.7	....	A	Yes							0	0	0		Repairs	0	0	......						
27.2	......					A	......	......	M	N										275	8	1n	.....	875	
	......	35.3	....	A	No								0	0		1-Cyl. and Piston	....	.....	.....						858
	......										1,181		0	0	4.37		....	.....	.....	313	8b	1	20	4,509	
26.7	61	29.4	....	A	No	B	......	......	L	N										156	8	1			
28.8	160	77.6	77.1	A	Yes	B	......	125	B	N	......	......	......	......	......	No Major Parts	0	0	......	213	8½	1n	.....	20	169
74.1	135	35.3	29.6	A	No	B	70	110	N	N	149	50	0	0	0.83	Piston Rings	2	2	98	105	8	1n	.....	730	677
																				117	9.7	1n			
66.8	160	63.0	66.8	A	No	B	90	130	N	N	52	20	0	0	0.32	P. R. & Spray V. Parts	0	0	......	312	8c	1n	.....	578	591
48.5	180	77.6	92.5	A	Yes	D	60	......	N	N	15	7	0	0	0.10	No Major Parts	0	0	......	66	....	1n	.....	190	984
	62	37.2	34.4	A	No						18	12	0	0	0.30	....	0	0	36						318
	33	29.4	28.8	A	No						4	5	0	0	0.18	....	0	0	10½						
	21	29.1	24.5	A	No						3	6	0	0	0.23	....	0	0	15	365	10	1			
	10	29.8	17.5	A	No						0	0	0	0	0	....	0	0	8	365	6	½			
....	62					A	50	140	B	N					0.23					365	8	½	.....	1,275	
64.0	115	29.4	25.2	A	No	A	55	110	N	N	63	46	0	0	0.54	1-Crank B; Minor Parts	0	0	62	351	8b	1n	.....	.....	1193
																				42	8	1n			
	66	37.2	36.7	A	No						0	0	0	0	0	None	0	0	0						733
	54	29.1	31.4	A	No						0	0	0	0	0	None	0	0	0						
53.2	120					A	......	......	N	N										.....	....	1	.....	850	
11.1	......	35.3	....	A	No	D-F	......	120	....	B	80				0.67	(See gg 18)	1	6	.....	365	12a	1n	.....	600	646
	10	32.3	19.0	A	No						8	0	0	0	0.08	None	0	0	......						1201
	23	37.8	17.4	A	No							0	0	0			0	0	......	365	12	1n			
....	23					B	65	108	N	N										365	12	1n	.....	3,400	

NOTES OF TABLE III

gg—Abbreviations—(A—Air); (B—Bearings); (C—Cooler); (Cp—Compressor); (F—Fuel); (H—Head); (L—Liner); (M—Manifold); (P—Piston); (Pu—Pump); (Pl—Plunger); (R—Rings); (Rb—Rebabbitt); (S—Seats); (Sc—Silencer Coils); (T—Thrust); (V—Valves); (W—Water).

*gg*1—6-Piston Rings; 2-Cooling Tubes; 10-lbs. Babbitt; 12-L. P. Valve Blades.

*gg*2—1-Cyl. Liner; 1-Cyl. Head Gasket; 2-Long Studs (Piston cooling); 2-Head Bearings; 55 lbs. Babbitt; 2-H.P. Valve Screws, 2-H.P. Valve Plates, 1-H.P. Cooler.

*gg*3—1-Cyl. Liner; 2-Crank Bearings; 5-Head Bearings; 1-H.P. Cooler (rebuilt); 1-Piston Cooling Tube; 1-H.P. Drain Valve; 3-H.P. Valve Screws; 3-H.P. Valve Plates; 10-Cyl. Head Gaskets; 9-Cyl. Liner Gaskets; 12-Piston Scraper Rings; 24-Piston Snap Rings; 12-Piston Double Seal Rings.

*gg*4—1-H.P. Cooler; 1-Main Bearing; 4-H.P. Valves (Suction); 4-H.P. Valves (Discharge); 6-Cyl. Head Gasket; 6-Cyl. Liner Gasket; 16-Piston Scraper Rings; 32-Piston Snap Rings; 16-Piston Double Sea' Rings.

*gg*5—1-Fuel Pump Plunger and Bushing; 2-Fuel Pump Springs; 1-Set Governor Balls and Separator.

*gg*6—Governor Spring Assem.; Exh. Valves; Piston Rings.

*gg*7—Crank Pin Bearing Bolts; Exh. Valve and Springs.

*gg*8—1-Liner; 1-Piston Pin and Bearing; 1-Set Governor Bevel Gears (10-Con. Rod Bearings, material gratis by manufacturer).

*gg*9—4-Cyl. Heads; 1-Piston; 2-Piston Rods; 2-Con. Rods.

*gg*10—1-Crk. Pin Bolt; Gov. Drive Gear; 5-SKF Bearings; 3 Rings.

*gg*11—1-Inj. Valve; 1-Receiver Hd.; 1-Comp. Piston; 1-Fuel Pump Plunger.

*gg*12—Rebabbitt 4 Cr. Pin Brs.; 1-Piston Pin Br.; 1-Cr. Pin; Fuel Pump Drive.

*gg*13—Rebabbitt Cr. Pin Brs. 10 Times; 17-Rings; 1-Comp. Liner and Rings.

*gg*14—Starting Head for 1 Cyl.; 1-Rocker Arm Bushing; 1-Speed Control Shaft.

*gg*15—1-Wrist Pin; 1-Cyl. with Piston Rings; 2-Crank Pin Bearings; Bushings; 2-Wrist Pin Bearings; 1-Wrist Pin; 1-Crank Pin Bearing.

*gg*16—1-Piston; 3-Wrist Pin; 2-W. P. Bushings; Gasket.

*gg*17—1-Cyl. and Piston; 3-W. Pins and Bushings; 1-Conn. Rod Bearings; Piston Rings; Gaskets.

*gg*18—4-Piston Rings; 4-Water Chamber Gaskets; 24-Cyl. Head Gaskets.

LETTERED NOTES

Injection System:
- A—Air
- M—Mechanical

Scavenging System (2 Stroke Cycle Only):
- C—Crank Case Compression
- P—Attached Pump or Blower
- B—Independently Driven Blower

Lubricating Oil Treatment:
- CC—Continuous Centrifuging
- BC—Batch Centrifuging
- Cent—Centrifuging (Kind Not Stated)
- C—Chemically
- F—Filtering
- S—Settling

Nature of Fuel:
- API—American Petroleum Institute
- B—Baume
- SSU—Seconds Saybolt Universal
- SSF—Seconds Saybolt Furol
- S—Sulphur
- CC—Carbon by Conradson Method
- BS&W—Bottom Sediment and Water

Piston Cooling:
- A—Air
- W—Water
- O—Oil

Heat Utilization:
- N—Not Utilized
- B—To Heat Building
- F—To Heat Fuel Oil
- L—To Heat Lubricating Oil
- T—Thawing Ice Cans
- P—To Process
- M—Boiler Feed Makeup
- W—Hot Water Supply
- S—To Swimming Pool

a—Cylinders Closed off from Crankcase
b—No Deduction Made for Motor-Driven Scavenging Blowers
c—60 Minute Peak Load
d—Before beginning of Reported Period (March 1st)
e—Injection Air Compressor Air is Filtered
f—Waited 870 Hours for Parts; This Time Included
g—Entire Labor Cost
h—No Deduction Made for Motor-Generator Excitation
i—Type A in Summer; Type B in Winter
j—Average for 24 Hours
k—Secondary Water also Soft
l—Recirculated; Temperature of Source

m—Semi-Diesel Engine
n—Part Time on Diesel Plant
o—K.W.; Direct Current
p—Changed under NRA; but Man-Hours Unaffected
q—Ice Plant attended also by Reported Staff
r—Summer-Winter Conditions
s—Does Not Include $1,885 for Cast Iron Piston Heads Replacing Steel; Made for Operating Reasons and charged to Capital Account
t—Arranged for Supercharging; Not Supercharged in Practice
u—Estimated
v—Installed in Plant No. 53 in 1926
w—Installed 25th Day of 5th Month of Period

x—Horizontal Engine
y—Supercharged to Give Sea Level Rating at 9,200 feet Altitude
z—Sold for 257 RPM; Operated at 234 RPM
aa—Date of first Installation; Installed in Plant 862 in 1928
bb—Belt Driven Generator
cc—Date Installed in Reported Plant; First installed Date Unknown
dd—Date of First Installation; Date Installed in Reported Plant Unknown
ee—Waited Two Weeks for Parts; This Time Included
ff—(a) indicates 2 similar shifts. (b) 3 similar shifts; (c) 4 similar shifts.